TEXTBOOK OF BIOLOGY

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LONDON

UNIVERSITY TUTORIAL PRESS LD.

Clifton House, Euston Road, N.W.1

Published 1935
Second Edition 1939
Third Edition 1943

N GREAT BRITAIN BY UNIVERSITY TUTORIAL PRESS LD., FOXTON
NEAR CAMBRIDGE

PREFACE

THIS book has been written with the object of presenting the subject of Biology—a subject of increasing importance —in an attractive and practical form.

Observational work is of the utmost importance in connection with the study of living things, and as far as possible plants and animals should be studied in their natural surroundings. This work must, however, be supplemented by the examination of specimens collected and suitably preserved if the internal mechanism is to be studied. In short, Biology is essentially a practical subject.

This book therefore has been written with the assumption that the student will have before him appropriate specimens and thus be able to follow the details from the actual parts of the plant or animal. A special feature of the book is the considerable number of clear illustrations which will assist the student in finding the parts discussed.

The book has been planned with the more essentially observational part of the work first, followed by the physiological part, which, although experimental, is in some ways also more theoretical. This section is better appreciated after the anatomical mechanism has been studied.

A dissection of an animal and a section of a plant part need more than one examination. Further, in the examination of another plant or animal many of the names will be repeated, and if the student makes annotated diagrams of his own specimens these terms will gradually become familiar and present no difficulty. It is suggested that too much time should not be spent on perfecting the anatomical work before considering the physiological section, since

it is beneficial to return to dissections and microscopic work after having considered more fully the functions of the several parts.

For the benefit of those intending to enter for examinations the syllabuses for the Intermediate Science, Pharmacy and Medical Examinations of the Universities of Great Britain, the Higher School Certificate, the Preliminary Medical, and other examinations of a similar standard have formed the basis for the choice of material to be considered. This naturally gives a good choice of animal and plant life and the material suggested for study is readily obtainable.

The authors wish to thank the University Tutorial Press for allowing them to use diagrams at present in the works of Wells and Davies, Lowson, and Cavers. We are also indebted to Miss W. M. Walley, and other students of the Norwood Technical Institute for assistance with the animal dissections and diagrams. We are very grateful to Dr. R. H. Whitehouse for helpful suggestions and criticisms, and for permission to reproduce Figures 143 and 144 from *The Dissection of the Rabbit.*

NOTE TO THE SECOND EDITION

For the Second Edition the text and figures have been thoroughly revised. Two new chapters dealing with Pine and Flowering plants have been added to meet the requirements of the Pharmaceutical Society's examinations, and in the Appendix some further hints are given with regard to the preparation of microscopic slides.

NOTE TO THE THIRD EDITION

In this Edition new matter and illustrations have been included in the form of an Appendix dealing with the edible snail—*Helix*.

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TEXTBOOK OF BIOLOGY

CHAPTER I

UNICELLULAR ORGANISMS

1. INTRODUCTORY

Biology is the science of living things, or the revelation of the life history of plants and animals, how they live, feed, grow, reproduce their kind, and what their work is in the Universe. The Universe is one vast harmonious whole; and everything, however large or small, whether living or inanimate, has its appointed part to play, and allotted place to fill. It is like an enormous spider's web, and just as every tiny mesh is necessary, and if broken or disturbed the whole web is affected, so it is with the Life of the Universe. Man, beasts, birds, fishes, insects, plants are all interdependent and interrelated and thus grouped together into one great whole.

Without plants, there could be no animal life, and without either, human life would also be impossible. We depend on plants and animals for our daily food; animals again live on other animals and plants, ultimately on plants, and these feed on the inorganic materials in the soil and atmosphere, which existed long before any living thing. Plants which possess green colouring matter, known as chlorophyll, are the only living organisms which can utilise the energy of the sun's rays to cause the direct combination of substances, which are entirely inorganic, to build up an organic molecule. The union of carbon dioxide and water which is brought about by a green plant in the presence of sunlight is the fundamental basis of all organic material.

The plant world is very vast, extending from the invisible " germ " of disease, many thousands of which must be placed end to end to make one inch, to the tall and stately tree, in the shadow of whose branches numerous birds and insects dwell. It may also provide shelter for many animals and even human beings. Similarly, animals vary from invisible specks of living matter to monsters like a whale.

As we consider plants and animals of more and more simple forms, we find that they gradually approximate to one another, until in the very lowly and simple forms, there is no sharp line of demarcation between them. It even becomes so difficult to distinguish a plant from an animal that there are still some organisms which are claimed as animals by zoologists and as plants by botanists. Prof. J. A. Thomson has very aptly said, " Plants move without changing their place, feel without nerves, feed without a stomach, live without knowing it, and die without caring." This is true in the majority of cases, but there are many plants, as we shall see later, in which the movement is accompanied by locomotion.

We may well begin our studies by examining the structure and following the life histories of some of the lowliest and simplest of living creatures. These, we find, require abundant moisture for their existence, so we turn to ponds, ditches, and damp situations generally.

2. AMOEBA

If a drop of pond- or ditch-water is allowed to settle, some small, greyish specks may be seen slowly moving at the bottom of it, but this will depend on the efficiency of the sight and on the size of the specks. In any case it is impossible to discover anything about them unless they are examined with a microscope. To do this a small drop of the water is placed on a microscope slide. This drop must be covered with a very thin square or circle of glass known as a cover-slip. In order not to crush the live

Amoeba the cover-slip must be supported at its ends on two others; another method is to use microscope slides which are hollowed at the centre, in which case the water containing Amoeba is placed on the cover-slip and inverted over the hollow.

A microscope slide should always be examined first with the low-power objective of the microscope. Then the high-power objective should be swung round to replace it in order to see the object in greater detail.

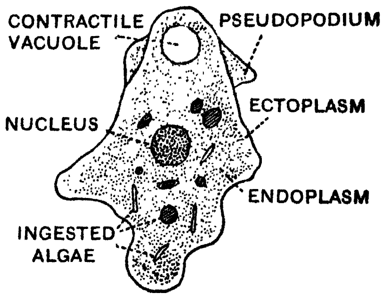


Fig. 1. AMOEBA.

The greyish specks are found to be very irregular in outline (Fig. 1), and as we watch them, the shape of each slowly changes (Fig. 2), causing this microscopic animal, Amoeba, to move across the field of view. A large number of tiny granules are visible in the animal's body, but all round the outline of it is a region fairly free from them and therefore clearer in appearance.

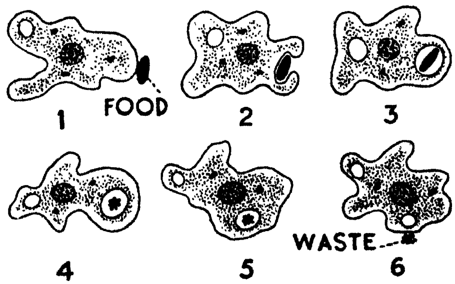


Fig. 2. AMOEBA CHANGES ITS SHAPE.

Amoeba consists of an irregularly-shaped mass of almost colourless, jelly-like material which can breathe, feed and grow, and is therefore alive. This material is called **protoplasm** (Gk. *proto* = first: *plasm* = matter). The clear outer region is called **ectoplasm** (Gk. *ecto* = outer),

and the remainder **endoplasm** (Gk. *endo* = inner). The animal moves by a portion of its body substance, or protoplasm, flowing in a certain direction. The remainder of the body slowly follows it. The portion that flows out is called a **pseudopodium** (Gk. *pseudo* = false: *podo* = foot). As pseudopodia are constantly being put out in various directions, the animal's shape is always changing. It can move in any direction because pseudopodia can be put out from any part of the body and in any direction. The living protoplasm can detect the presence of certain substances, so it is said to be sensitive to certain stimuli. In consequence Amoeba will move towards oxygen and food, and away from a hard or sharp object, a very strong light, solutions of salts, acids, and sugar.

By more careful examination of the body there may be seen in it a darker and more dense portion, rounded in outline, with possibly one or more dark specks in it. This is a special piece of living substance called the **nucleus,** and it controls all that is done by the protoplasm. A detached portion of protoplasm containing a nucleus is the **unit of life,** and is called **a cell.** Thus Amoeba is an animal consisting of just one cell, that is, a unicellular animal. Also in the protoplasm one, or sometimes two, round spaces occur. These are called **vacuoles** because of their appearance of emptiness. Actually they contain a colourless liquid.

One of these vacuoles may contain a small dark object, and this will be a portion of food. Amoeba feeds on salts dissolved in the water, which diffuses into and permeates its body, and also on water-plants and water-animals tinier than itself. These organisms are obtained by the Amoeba flowing round them and engulfing them into its body (Fig. 2). A food vacuole forms around them, and here they are digested, that is, rendered soluble by digestive fluids secreted by the protoplasm into the food vacuole. Any useful substance formed by protoplasm is called a

secretion and said to be secreted. The parts of the food that cannot be made soluble are waste, and any waste product must be removed from the body. Amoeba gets rid of portions of solid waste material by simply flowing away from them; this is called egesting them.

The second vacuole is seen continually to appear and disappear, and is therefore called the contractile vacuole. It discharges its contents at the surface of the animal's body and then gradually re-forms. It is probable that Amoeba excretes its liquid waste products in this way.

An animal must have food in order to acquire energy. To supply this energy the complex chemical compounds in the food are broken down into simple ones, including uric

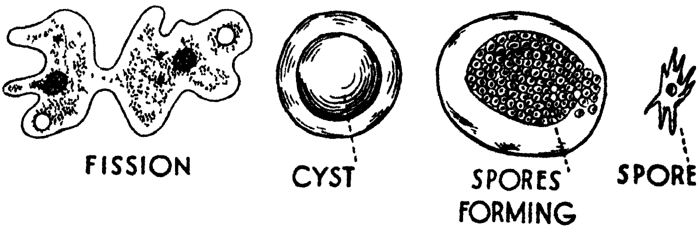


Fig. 3 Reproduction of Amoeba.

acid, carbon dioxide, and water. This breaking down causes energy to be liberated, but in order to effect this oxygen is needed. The taking-in of oxygen and giving-out of the waste products, carbon dioxide and water, is called breathing or respiration. Amoeba respires all over the surface of the body, since, over its whole surface, oxygen dissolved in water enters, and carbon dioxide dissolved in water passes out. The main excretion of the contractile vacuole is water, but it also excretes organic substances and probably carbon dioxide, so that it may be connected with respiration.

All animals reproduce their kind, that is, give rise to others which are called their offspring. When Amoeba is

fully grown its body, including the nucleus, eventually just divides into two (Fig. 3). Thus, except for accidents, an Amoeba is immortal, since instead of dying of old age it becomes two. This method of reproduction is called **simple fission.**

If Amoeba is submitted to adverse conditions, such as cold, drought, or starvation, it becomes a round mass and secretes around itself a tough case called a **cyst.** In this condition it remains alive, but inactive, for a very long time. It may get blown about and thus reach another habitat. Eventually, when conditions are favourable, the tough coat bursts and Amoeba emerges. Sometimes while thus encysted the protoplasm of the Amoeba divides into a number of tiny pieces, each containing a nucleus. These are called **spores,** and each one on emerging forms a new Amoeba.

3. CHLAMYDOMONAS

Also living in fresh water may be found **Chlamydomonas,** whose presence gives the water a green colour. If a drop of the greenish water is placed on a slide and examined with a microscope, a number of oval-shaped organisms can be seen. They are narrower at one end than the other and each has a firm, even outline. This outline consists of a substance called cellulose, which forms the **cell-wall** (Fig. 4, A). Each organism is one cell and is like a tiny balloon of cellulose inside which the protoplasm forms a network. At the wider end of the cell there is a large green patch. This consists of protoplasm permeated with green colouring matter, called **chlorophyll,** and is therefore known as a **chloroplast.** If a Chlamydomonas were cut in half lengthwise the chloroplast would be seen to be basin-shaped. Partly in the hollow of the basin lies the nucleus.

In the chloroplast there is a large, round, colourless portion called a **pyrenoid,** the centre of which consists of

protein. If iodine solution is drawn under the cover-slip, by placing a drop of it against one side of the cover-slip and a strip of blotting-paper against the opposite side, a number of blue spots will be seen around the pyrenoid. Iodine stains starch blue; thus it appears that the pyrenoid is the centre of the starch formation, which is an important part of the life of all green plants.

Green colour is associated with plants, and therefore it is easy to call Chlamydomonas a plant; but a surprising feature that no plant is expected to possess is the power of being able to swim freely in the water. On very careful examination two very fine threads of protoplasm can be

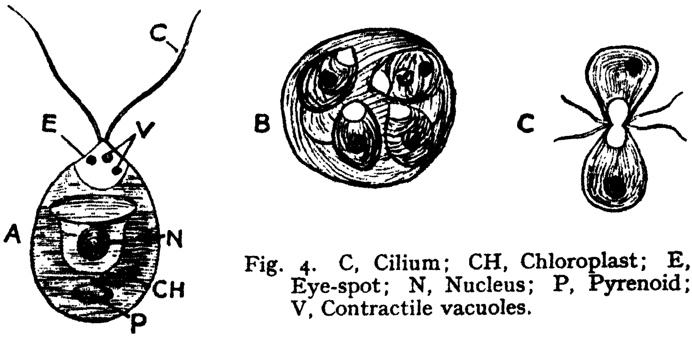


Fig. 4. C, Cilium; CH, Chloroplast; E, Eye-spot; N, Nucleus; P, Pyrenoid; V, Contractile vacuoles.

seen protruding from the more pointed end. Each is called a **cilium.** By lashing the water, they cause the plant to rotate and force its way through the water by a corkscrew-like movement. Thus Chlamydomonas always moves along with its more pointed end forward, so that it has an **anterior,** or front, end and a **posterior,** or hind, end.

Close beneath the cilia can be found a tiny red spot. This is sensitive to light, causing the plant to move towards light usually, but away from a very brilliant light. Here, then, is something that slightly resembles an eye in its function, and it is therefore called an **eye-spot.** Close by it are two tiny **contractile vacuoles.** These act in the

same way as the similar vacuole in Amoeba, being concerned either with excretion of waste, respiration, or both; but organic substances are not excreted as waste products from a plant.

Chlamydomonas being a green plant its food consists entirely of inorganic substances, namely mineral salts and carbon dioxide. These are dissolved in the water and pass in through the cell wall. With these simple compounds the plant is able to build up complex substances which enter into the composition of the living protoplasm. This building up can only occur if some form of energy is supplied. When we wish two substances to combine chemically we heat them and thus supply energy. The plant uses the radiant energy of the sun and this is captured by the chlorophyll.

When Chlamydomonas is about to reproduce, it withdraws its cilia through the cell wall and assumes a round shape. If conditions are favourable, that is, if the organism is well supplied with food, air, and warmth, the contents divide into two, four, or eight parts (Fig. 4, B), each containing a portion of the nucleus and the chloroplast. The cell wall breaks and these separate pieces escape. Each develops a pair of cilia, secretes a cell wall, and gradually attains the full size of an adult Chlamydomonas. These small portions which are thus capable of forming new plants are called **zoogonidia**; and this method of reproduction is *asexual*.

If conditions are unfavourable the method of reproduction will be *sexual*. The individual plants become round, and the contents divide into any number up to sixty-four pieces, which are shortly liberated in the water and develop cilia. The water therefore contains a large number of tiny organisms similar to an adult Chlamydomonas but with no cell wall. These come together in pairs at the pointed end (Fig. 4, C); one of each pair is regarded as male and the other as female, but it is impossible to

distinguish between them. They are called **gametes**, and because the male and female are exactly alike the sexual reproduction is said to be **isogamous.** The two gametes fuse with one another, their nuclei and chloroplasts uniting to make one, and the resulting structure is called a **zygospore.** A thick coat is secreted around it, and it rests for a period.

Sexual reproduction has two distinct advantages. The zygospore can withstand adverse conditions for a prolonged period; and by the union of two gametes, probably from two different Chlamydomonas plants, any good characters, such as resistance to disease, possessed by the one and not by the other, may be present in the resultant offspring and may mitigate weak or inferior characters.

When the period of rest is over the thick coat breaks, and the contents of the zygospore escape into the water. Two cilia and a cell wall develop so that a new plant is formed.

4. HAEMATOCOCCUS PLUVIALIS OR SPHAERELLA LACUSTRIS

A pool of standing water sometimes assumes a reddish tinge, which is usually due to a small plant very similar to Chlamydomonas. This plant is also found in snowy districts and gives the appearance of a streak of blood, from which arose the name **Haematococcus** (Gk. *Haemato* = blood). On examination under the microscope it is seen to be the same shape and to have a pair of cilia (Fig. 5). Usually little else can be seen owing to the red colouring, **haematochrome,** which permeates the protoplasm. Between the coloured protoplasm and the cell wall is apparently a space. This consists of mucilage and is traversed by threads of protoplasm (Fig. 5, A). The chloroplast is a hollow network lying close to the outer edge of the protoplasm. There are several pyrenoids in the chloroplast and numerous contractile vacuoles in the protoplasm. The nucleus is more or less central, and an eye-spot occurs at the anterior end.

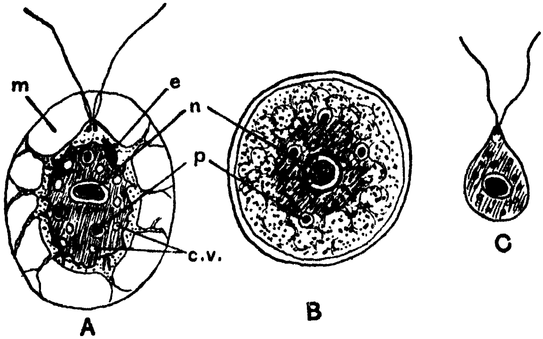


Fig. 5. SPHAERELLA.

A, Motile cell; B, Resting cell; C, Gamete; n, Nucleus; p, Pyrenoid; c.v., Contractile vacuoles; e, Eye-spot; m, Mucilaginous layer. Cytoplasm dotted in A., Chloroplast line-shaded.

When about to reproduce, Haematococcus forms a round resting cell (Fig. 5, B), and the contents divide into zoogonidia, or into gametes.

5. PROTOCOCCUS VIRIDIS OR PLEUROCOCCUS VULGARIS

There is a green growth frequently seen on tree trunks and wooden fences called **Protococcus viridis** or **Pleurococcus vulgaris.** It only appears if the tree trunk or fence is usually damp, and therefore it is seen only on the side against which the rain is driven by the wind. This growth, examined under the microscope, is seen to consist of a number of unicellular plants, more or less round in shape. Each contains one large chloroplast which is lobed (Fig. 6). In addition to single cells, as shown in the figure, cells occurring in twos and fours are usually present. When it is

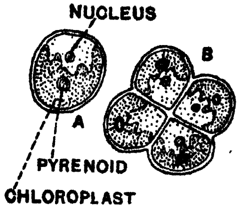


Fig. 6. PLEUROCOCCUS.
A, Single cell; B, Group of cells.

ready to reproduce, the contents of a Protococcus divide into two parts, and each part secretes around itself a new cell wall. Sometimes the two new individuals thus formed remain adjacent to one another, and when these in their turn reproduce, four cells remaining together result. Protococcus plants thus tend to form colonies.

6. EUGLENA

Unicellular organisms known as **Euglena** are very commonly found in stagnant water, ponds, or ditches, particularly where there is abundant organic matter present. They are too small to be seen individually with the naked eye, and must therefore be mounted on a slide and examined microscopically. Each is spindle-shaped, and has one long, strong swimming organ known as a flagellum (Fig. 7). Unlike Chlamydomonas, Sphaerella, and Protococcus it has no cellulose membrane covering it, but simply a rather thick outer layer to the protoplasm, which is spoken of as a **cuticle**. Thus the cell wall so characteristic of plants is absent, and this allows contraction and dilatation of the body to occur freely, particularly in the posterior portion. This flexibility of the body is spoken of as euglenoid movement.

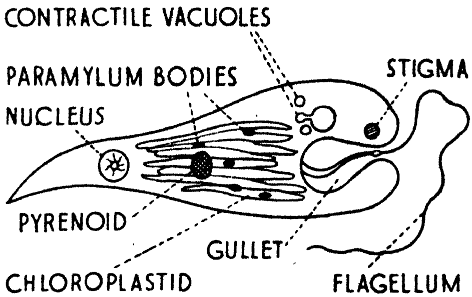


Fig. 7. EUGLENA VIRIDIS.

The flagellum by means of which the plant moves forward, arises from the side of a little depression, which has been called the **mouth**, and which is continued into the protoplasm as a minute tube, known as the **gullet**. The organism is enabled by the mouth and gullet to take

in and digest solid food; this is a very distinct animal character. Near the inner end of the gullet is a spherical vacuole, which varies very little in shape or size. Smaller contractile vacuoles communicate with it, and it, in its turn, communicates with the gullet and serves as the means whereby excretion products are removed.

Like other unicellular organisms Euglena has a distinct nucleus, which is situated near the posterior end. In common with actively-swimming unicellular creatures it has a red eye-spot, which here has been called a stigma; this is a spherical body containing a number of minute granules of a red pigment, haematochrome, which, like chlorophyll, is soluble in alcohol and ether, but is insoluble in ammonia and acetic acid.

The most common Euglena is **Euglena viridis,** and this one contains several rod-shaped **chloroplasts** making it quite green in colour and thus to resemble plants. These chloroplasts also possess a body resembling a pyrenoid such as is found in chlamydomonas; further they are associated with the formation of a carbohydrate, known as **paramylum.** Thus when external conditions are suitable, Euglena viridis can feed, like plants, on carbon-dioxide and mineral salts dissolved in water.

Like Amoeba, when it is ready, it reproduces itself by **fission,** *Euglena viridis* assuming a spherical condition in a similar way to Chlamydomonas and Sphaerella before the division occurs. More than one division may occur before the new Euglenas escape and swim about. There are some forms of Euglena which divide by longitudinal fission, *i.e.* the nucleus divides and then the body divides lengthwise without any fundamental change in shape occurring. When, owing to the season or any other cause, conditions are unfavourable, the cell becomes enclosed in a **cyst** with an outer resistant envelope, yellowish-brown in colour. Division ultimately occurs within the cyst and the new Euglenas are liberated.

Euglena viridis is an organism possessing a combination of distinctive plant and animal characters, and may therefore be considered to be somewhat intermediate between these two great groups.

7. PARAMECIUM

There is a minute animal called **Paramecium**, which occurs in the fresh water of ponds, and so on. It is just visible to the naked eye as a whitish spot. Seen under the microscope it is in rapid motion, soon passing out of the field of vision unless the slide is moved.

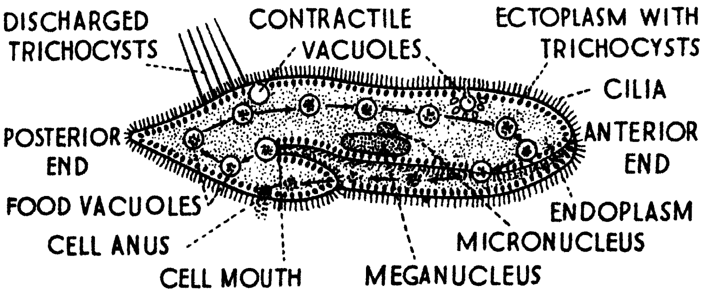


Fig. 8. PARAMECIUM.
(After Parker.)

In shape it resembles the side view of a slipper upside down, and hence is known as the slipper animalcule. It moves with the rounded end forward so that this is anterior. It is bounded by a definite outline, the **cuticle**, which is denser protoplasm, not cellulose like the cell wall in plants. Projecting through the cuticle is a very large number of protoplasmic threads (Fig. 8) known as cilia, which, by their lashing movement, cause the animal to rotate, and drive it forward through the water. In addition to posterior and anterior ends, in this animal an upper, or dorsal, surface and a lower, or ventral, surface are distinguishable. The last is somewhat flattened and contains a groove.

The protoplasm immediately under the cell wall is clearer, so that there are ectoplasm and endoplasm as in Amoeba. In Paramecium small, regularly-placed bodies called **trichocysts** occur in the cytoplasm, which, if the animal is irritated, shoot out long, firm, pointed threads. They are probably used either for attacking, or in self-defence, or for both purposes. Paramecium is somewhat unusual in having two nuclei, a small **micronucleus** and a larger **meganucleus.**

At the bottom of the groove on the ventral surface is a tiny area with no cuticle, and here the animal takes in food, so that this spot functions as a mouth. Being an animal, Paramecium requires organic food in the shape of other minute creatures, such as bacteria which occur where anything is decaying. The groove is lined with cilia which assist in sweeping the food into the mouth. On entering the protoplasm a food vacuole forms around the food, which gradually circulates right round the body, as shown by arrows in the diagram. The undigested, that is waste, material is ejected through the cell wall at a place that can be called the cell anus. The contents of a food vacuole are at first acid and later alkaline. There are two contractile vacuoles close to the dorsal surface, one near the anterior and the other near the posterior end of the animal, and when fully expanded these vacuoles have a centre part surrounded by rays.

Each Paramecium is capable of dividing into two by **transverse fission.** Each nucleus divides into half, and a groove appears around the centre of the body and deepens until the body is halved. Thus each new animal must develop new parts since each has only one contractile vacuole and one has no mouth.

When reproduction of this type has been going on for some time the individuals become small and weak generally. The race would therefore be in danger of extermination if *sexual reproduction* did not occur to bring it back to its

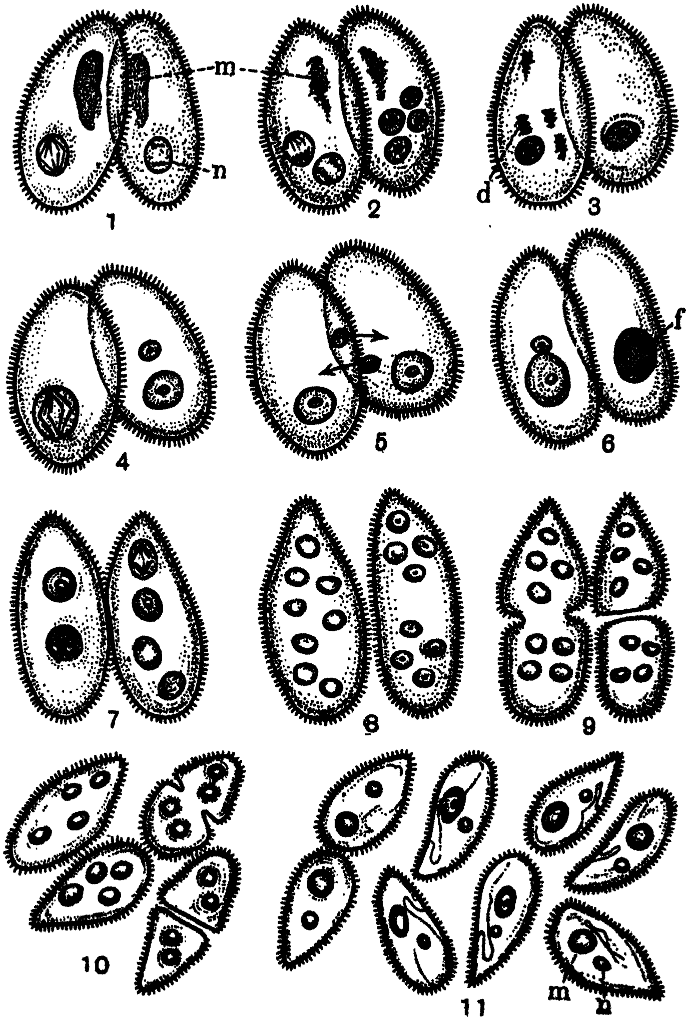


Fig. 9. PARAMECIUM.
Semi-diagrammatic series to show stages in sexual reproduction: m, Meganucleus; n, Micronucleus; d, Nuclei disintegrating; f, Fusion nucleus.

old level of efficiency. In this process characters from two individuals are brought together. Thus sometimes the new organism will have a double set of good characters or a good character may be brought to combine with a bad one and thus counterbalance it. In sexual reproduction two animals become joined to one another at the mouth. The meganuclei of the two individuals gradually disintegrate, and this would indicate that they are concerned only with the ordinary daily life of the individuals and not with reproduction. The two micronuclei each divide into four (Fig. 9), but three of the four thus formed disintegrate, leaving each individual with one nucleus (Fig. 9, 2 and 3). Each of these two nuclei then divides into a small portion and a larger portion. The small nucleus from each individual then passes over into the other one and when this interchange has occurred the two nuclei in each individual fuse and the individuals separate from one another. The process of interchanging and fusing of nuclei is called **conjugation.** When the conjugants have separated, the nucleus of each divides into eight, the body divides into two, and each of these halves into two again. Thus there result finally four individuals each with two nuclei, one of which becomes the micronucleus and the other the meganucleus. The other conjugant behaves similarly, so that from the union of two individuals, eight are formed in the next generation.

8. A MICROSCOPE SLIDE

When examining live animals or plants it is useful sometimes to support the cover-slip as described or use hollowed slides. Otherwise flat microscope slides are used. The drop of liquid with the specimen should be placed at the centre of the slide and covered with a cover-slip. To prevent the inclusion of air bubbles, place the cover-slip with one edge touching the liquid and use a mounted needle as a lever at the other side.

CHAPTER II

CELLS AND CELL DIVISION

1. YOUNG PLANT CELLS

The animals and plants so far considered have consisted only of one cell, which was therefore concerned with all the life processes necessary for an organism to live and reproduce its kind. As plants and animals become larger, they cease to be composed of one cell, but many such units are needed to make their bodies. With increase in the number of units making one plant or one animal, there comes division of labour, some cells being specialised to do the work of feeding, others that of reproduction, and so on.

A typical young plant cell consists primarily of three parts—protoplasm, cell sap, and cell wall. The living substance, **protoplasm**, is a substance of a somewhat slimy consistency, and as microscopes and micro-technique have improved, gradually more and more has been discovered about its structure. It is not homogeneous, and it has been described in three different ways, namely, as a gelatinous substance in which are embedded numerous very small granules; as a network of extremely fine threads arranged in a gelatinous matrix; and as a honeycomb structure filled with a gelatinous substance. A substance which greatly resembles protoplasm in general appearance may be obtained by taking a few drops of olive oil and pounding with them a little potassium carbonate until a creamy paste results, and adding a little water. At first a number of bubbles are formed, each containing a minute quantity of potassium carbonate; into these, water gradually diffuses, dissolving the potassium carbonate and producing a frothy liquid. If this is then left for twenty-four hours, each drop has the appearance of protoplasm and moves in

the same way as a naked cell, but cannot assimilate food, grow, or reproduce itself.

Protoplasm is essentially protein in composition and belongs to the class of chemical substances known as **colloids.** Gelatine is a colloid, and from this form it acquires its characteristic properties. Colloids usually have very large molecules, but only a few molecules are aggregated together to make a particle, so that the latter is very small. In fact the particles are so small that the surface area relative to the mass is so large that they do not respond to gravity, the surface tension and attraction of the neighbouring particles having the greater influence. The result of this is a jelly-like condition or emulsion. The white of an egg, soap, and rubber are familiar colloids. The strength of a cobweb arises from its colloidal nature, and artificial silk is made from cellulose in this form.

The particles of a colloid, owing to their great attraction for one another, make a kind of surface film, which is very important in connection with protoplasm. Colloids do not pass through membranes, and diffuse only very slowly; these are important factors in helping protoplasm to maintain its identity. Some particles may unite into a firm jelly, or " gel," and in this way protoplasm can build up internal structures.

The specialisation of the surface layers gives to colloids generally, and protoplasm in particular, a very great power of absorption, that is attracting certain substances into the surface film, where they may be retained, enter into reaction with other substances, or pass through. This process is fundamentally important in connection with the obtaining of food, removal of waste, and protection of the living organism. The limiting layer of the protoplasm is called the **plasmatic membrane.**

When chemically analysed, protoplasm is found to contain the elements carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. The proportions of these can

be determined and a substance which will give an exactly similar chemical analysis can be synthesised, but again it has not yet been found possible to produce a living substance.

The general mass in the cell is known as the **cytoplasm,** and in it is a prominent body of a much denser character, the **nucleus,** which is the centre of the activity of the cell. The nucleus is a specialised portion of protoplasm, containing a larger proportion of phosphorus, separated from the cytoplasm by a membrane, known as the nuclear-membrane. It contains a number of denser thread-like structures, which are very readily stainable with aniline dyes and are known as **chromatin fibrils,** and one or more spherical structures, also of a very dense nature, known as **nucleoli.** The nucleus controls the work of the cell, and without it one cell could not divide into two. In addition to the nucleus, there are also a number of smaller bodies embedded in the cytoplasm, known as **plastids,** which have special functions to perform. Amongst the plastids are the chloroplasts which contain the green colour, so characteristic of plants.

Outside the protoplasm of a plant cell is the **cell wall.** This has been secreted by the protoplasm, and in the young cell it is composed of a carbohydrate, known as cellulose.

That the protoplasm is the living material of the cell may be readily appreciated by taking a leaf from the water-plant *Elodea,* Canadian Water-weed, mounting it in water, and examining it under the microscope. If the temperature is sufficiently warm, all the little solid plastids in the cells will be seen to be carried round and round the cell by a very definite current. The protoplasm is moving rhythmically round the cell, carrying with it all the plastids and granules. The latter arrest the attention, because they are more readily visible, but if the movement be carefully examined it will be seen to be a regular harmonious flow of the whole cytoplasm.

2. THE DIVISION OF VEGETATIVE CELLS

For the examination of nuclear division, it is advisable to purchase specially-stained sections. Good sections can be prepared from root-tips of onions, hyacinths, etc., stained with iron haematoxylin. (See Appendix.)

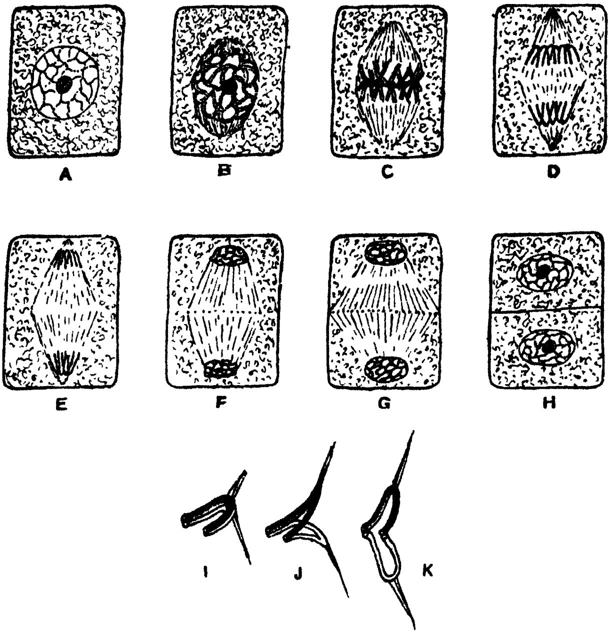


Fig. 10. A-H, Stages in Karyokinesis and Cell-division. I-K, Longitudinal Splitting of a Chromosome.

When a cell is about to divide, changes are initiated in the nucleus (Fig. 10). The nucleus becomes larger and the fine chromatin network present in the resting cell thickens and opens out into a convoluted thread. This is known as the **spireme stage.** Later the thread becomes divided into a number of thicker parts, connected by very thin ones, and eventually it breaks into a number of

irregular bodies. These then assume the form of short, thick filaments, known as **chromosomes.** In any particular plant the same number of chromosomes is always separated out during nuclear division.

These are a very important part of the unit of life, because it is believed that in them the hereditary characters, which are needed to continue the particular form of plant and animal from one generation to another, reside. Further, it is due to new combinations of the chromosomes in sexual reproduction, that new forms come into existence.

Each chromosome undergoes a longitudinal split, but the two parts remain side by side as they move to the plane of division, namely, the equatorial plate. Cytoplasmic filaments then become applied to the nuclear membrane, and surround it with a fibrous layer which becomes raised at two poles, from which filaments diverge to form the **nuclear spindle.** Whilst this is taking place, the nucleolus disappears, having helped to make the spindle. The daughter chromosomes formed by the longitudinal split separate from one another, and one of each pair travels to one pole of the nuclear spindle and the other to the opposite pole. The free ends of the chromosomes then become drawn in, and a reticulate network is produced in a nuclear cavity round which a membrane develops. At the same time the surrounding cytoplasm becomes separated to form two parts, each of which surrounds one of the daughter nuclei.

When the chromosomes leave the equatorial plane, a little swelling is visible on each of the spindle threads; this is the beginning of the **cell wall,** which is laid down to separate the two masses of cytoplasm each with its nucleus, and to make each into a daughter cell completely surrounded by a wall of its own, like the mother cell from which it was produced. When the two daughter nuclei, in their turn, divide, the chromatin network separates into the same number of chromosomes as had appeared in the mother cell from which they were produced. This

type of division is known as **karyokinesis** (Gk. *karuon* = a nucleus: *kinesis* = movement), or **mitosis** (Gk. *mitoo* = to weave thread).

3. REDUCTION DIVISION OR MEIOSIS

During the consideration of the simple plants and animals described in Chapter I., it was noticed that sexual reproduction, involving the union of two units known as gametes, generally occurred. Each gamete has a nucleus, together with some protoplasm, and these two substances mingle with the corresponding ones in the other gamete. Now if there are six chromosomes in the male gamete and six in the female, there will be twelve in the resulting zygote. Similarly, if there are twelve in each gamete, there will be twenty-four in the zygote, and so on. During the process of karyokinesis it was noticed that the number of chromosomes remained unaltered. It follows therefore, if succeeding generations are to have the same number of chromosomes a different type of nuclear division must occur somewhere to balance the effect of sexual reproduction. Such a division is spoken of as **reduction division** and is part of **meiosis.**

In this type of division the chromatin thread becomes distinctly defined and a longitudinal split is initiated as in karyokinesis. A spindle also is formed and the chromosomes arrange themselves along the equator of the spindle as before. When they begin to separate a change is seen; a whole chromosome, instead of half a one, travels along each spindle thread (Fig. 11). The result of this is that when the separation is completed, half the original number of chromosomes are at one pole of the nucleus and the other half at the opposite pole. The nucleus formed by the union of these chromosomes has therefore had its number of chromosomes reduced by half. Hence the term reduction division arises. The two nuclei so formed do not enter into a state of rest, but as soon as the chromatin

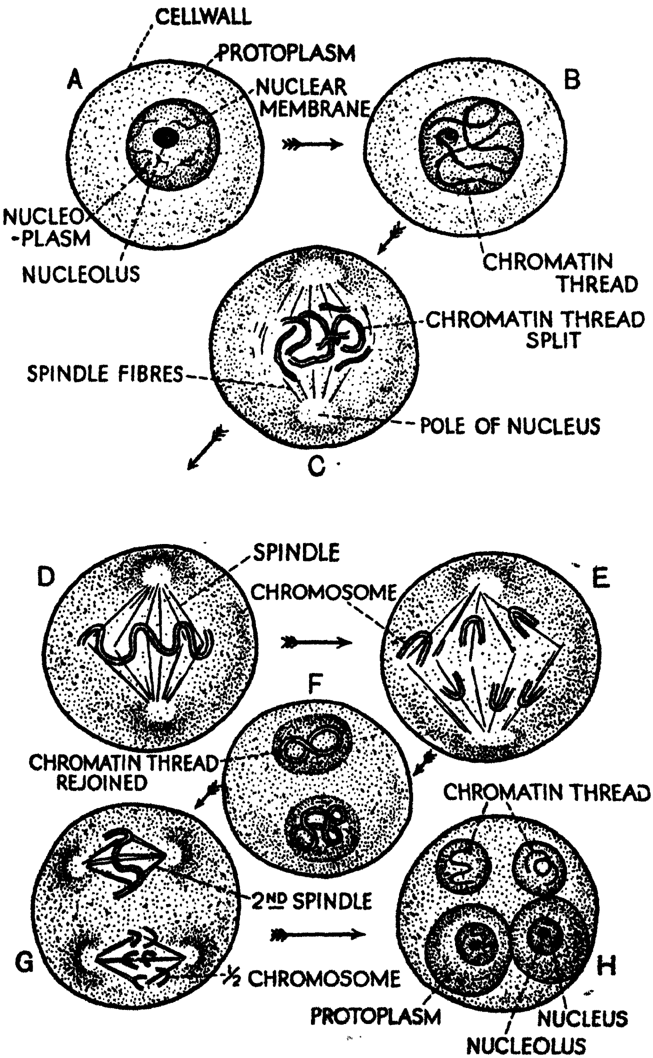


Fig. 11. Stages in Reduction Division.

thread has been re-organised, another spindle begins to form in each case. The chromosomes arrange themselves along the equator, the longitudinal split which became apparent in the early stages of the previous division

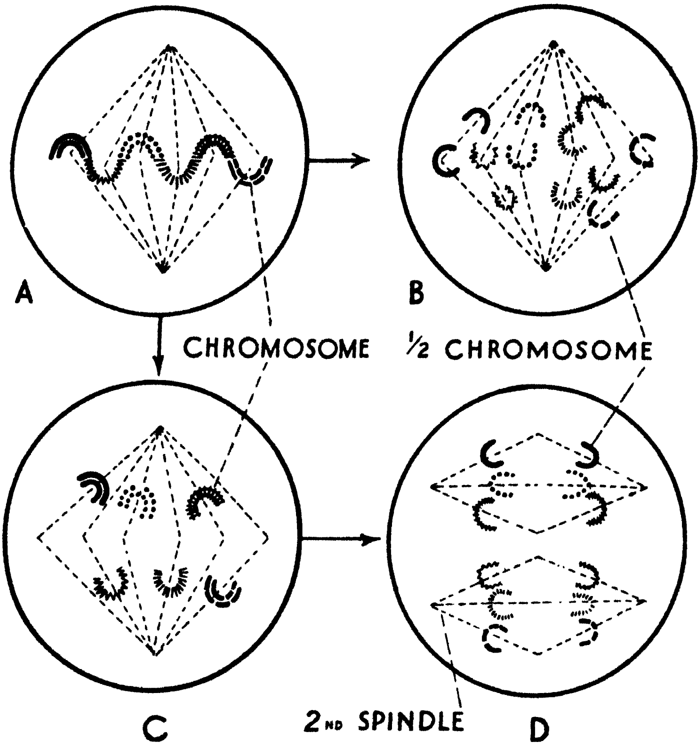


Fig. 12. Plan to show Chromosome Relation in Karyokinesis in A and B, and in Reduction Division in A, C, and D.

takes effect, and half of each chromosome travels to the poles of this new spindle. There are now four nuclei present, each with half the number of the chromosomes possessed by the original nucleus, and these nuclei enter into a state of rest, each with its attendant cytoplasm, to

make the complete cell. The whole series complete to the production of four nuclei is **meiosis.** This type of division is well seen in the anthers in sections prepared from flower-buds and stained with iron haematoxylin. Specially prepared slides are advisable for studying this.

From the point of view of characters, when the chromosome is divided longitudinally it is thought that all the characters present in one half are also present in the other half, but in the first division of meiosis there is a sorting-out of characters, because the entire chromosome with its characters is present in one nucleus and not in the other (Fig. 12, C, D). Herein lies the possibility of separation of certain characters and the mingling together of different ones.

4. CELL DIVISION IN ANIMALS

It was seen in Chapter I. that the unicellular animals contain protoplasm and nuclei in a similar manner to the unicellular plants. These are the fundamental living parts which grow and multiply whether the organism be animal or plant. Nuclear division is the beginning of the formation of two units in place of one, and in animals **mitosis** and **meiosis** occur in a similar way and with the same significance.

In many animal cells a minute spherical body occurs just outside the nuclear membrane. This is called a **centrosome.** It is a body which only becomes prominent in connection with cell division. It divides into two parts, each of which travels to the poles of the nucleus and becomes the centre from which the spindle fibres radiate.

In animal cells no cellulose membrane occurs round the cytoplasm; consequently no membrane is formed across the equator of the spindle, although the two masses of cytoplasm separate there.

CHAPTER III

SIMPLE MULTICELLULAR PLANTS AND ANIMALS

1. MOTILE COLONIAL PLANTS

Chlamydomonas is a small unicellular motile plant. There are many instances in fresh-water organisms where several similar motile cells have remained attached to one another to form a larger, motile plant. Thus 8, 16, or 32 such cells are collected together into a compact spherical colony in **Pandorina** (Fig. 13). In **Eudorina** 32 cells are much more distantly placed in a mucilaginous envelope making a spherical colony. **Pleodorina** shows a similar grouping of motile cells, but they are no longer all alike, some being much smaller than others. In this case only the larger cells, which are in the posterior half, are capable of taking any part in reproduction. This type of development culminates in **Volvox,** where several thousand cells may take part in making the colony, some of which are vegetative, some associated with sexual, and others with asexual, reproduction (Fig. 14). Thus in this group of motile plants, although they are all quite small, only Volvox being distinctly visible to the naked eye, there is division of labour among the cells so that they may become specialised for certain functions.

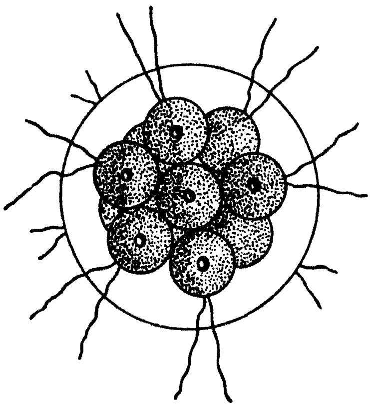


Fig. 13. PANDORINA.

In all these colonies the cells are green and possess two cilia peripherally, the movement of which gives the whole plant the power of locomotion. In Volvox the cells are held together by protoplasmic strands in addition to the mucilaginous envelope in which they remain embedded.

These plants all have the power of forming new colonies by one cell dividing into as many units as are required. These are spoken of as **daughter colonies.**

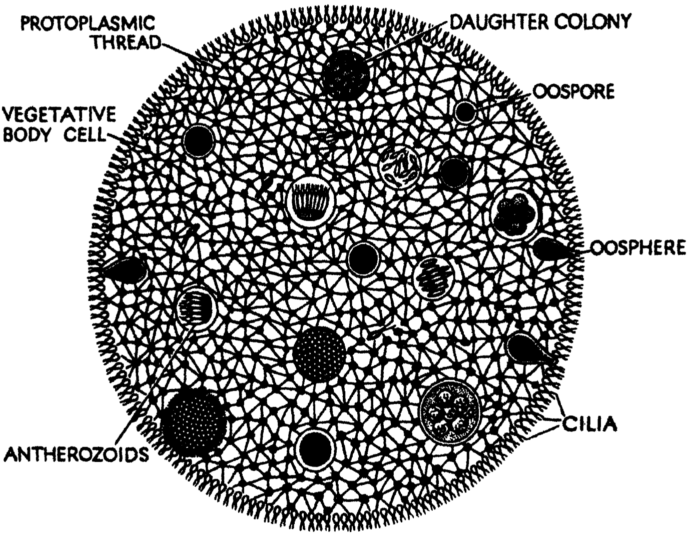


Fig. 14. Volvox.
(Diagrammatic to show reproductive bodies.)

Sexual reproduction also occurs in all cases. In Pandorina biciliate gametes are formed similar to those formed by Chlamydomonas, but when they conjugate in pairs it is seen that one is rather larger than the other. This is considered to be the female one. The smaller male one is more active. This distinction of the gametes becomes more pronounced in other forms, so that in Eudorina and Volvox only one female gamete, known as an **oosphere,** is formed

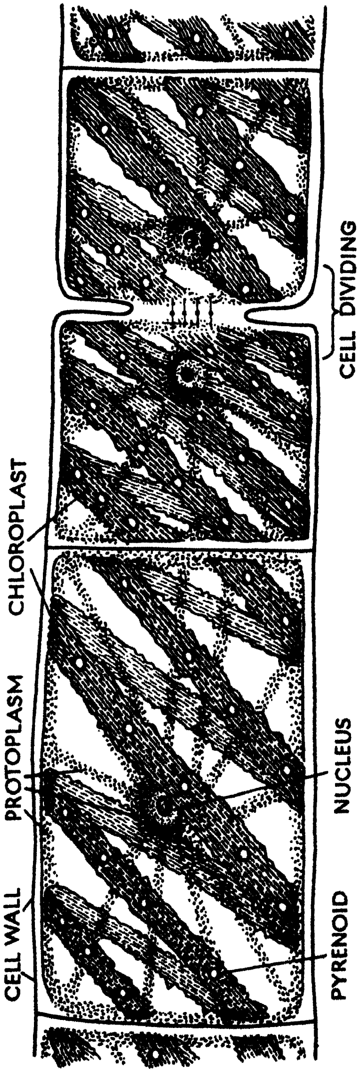


Fig. 15. Spirogyra.

in one cell called an **oogonium** (Fig. 14), while many biciliate male gametes, called **antherozoids,** are formed in one cell called an **antheridium.** In Volvox the cells which will become oogonia or antheridia are set aside at the beginning of its life. Only the male gametes are liberated, and they swim to the oosphere which remains a part of the parent colony. This type of sexual reproduction is said to be **oogamous.** The fertilised cell, or **zygote,** formed by this union is known as an **oospore.** The oospore forms a special wall around itself, and later forms a daughter colony.

In Volvox the daughter colonies are liberated into the hollow interior of the parent, where for a time they are sheltered and grow. When many new colonies have been produced, the parent disintegrates and they are liberated.

In this little group of motile plants there is an increasing complexity of the vegetative body from Chlamydomonas to Volvox, and also a transition from **isogamous** sexual reproduction in the former, to **oogamous** in the latter.

2. SPIROGYRA

Spirogyra is a green filamentous plant growing in ponds and characterised by being very slimy to the touch. Each filament is a plant and consists of a single row of cylindrical cells placed end to end. Each cell is exactly similar to its neighbours, each has its own vegetative period of life, and each, in turn, may play a part in the reproductive phase of the plant. The cells are characterised by the possession of a chloroplast, which has the form of a spiral band, wound immediately inside the cell wall (Fig. 15). Embedded in the chloroplast are a number of small, oval pyrenoids, each of which is connected with the nucleus, which occupies the centre of the cell, by a very fine protoplasmic thread. The nucleus undergoes karyokinetic division and the cell wall grows across from the edges to the centre. The filament may break between any two cells and thus produce two filaments instead of one. This process is termed *vegetative reproduction.*

Sexual reproduction also occurs, in which case the cells of a filament become very modified. First of all the spiral chloroplast loses its definite form and gradually the whole cell contents become wound up into an oval mass (Fig. 16). At the same time two filaments have approximated one another and lie side by side. On the side of the filament which is nearest the other filament, the cell wall sends out a protuberance.

These protuberances grow towards one another, and eventually meet. Later the cell wall between them breaks down, and the cell in one filament is now continuous with a cell in the other filament. The oval mass in one

cell moves across the narrow passage into the other cell. Generally all the cells in one filament become empty, while each of the cells in the other holds the contents of two original cells, that is the two gametes. These two structures unite together conjugating completely to form one zygote, or spore, produced by sexual union. It is noteworthy that the gametes are exactly similar to one

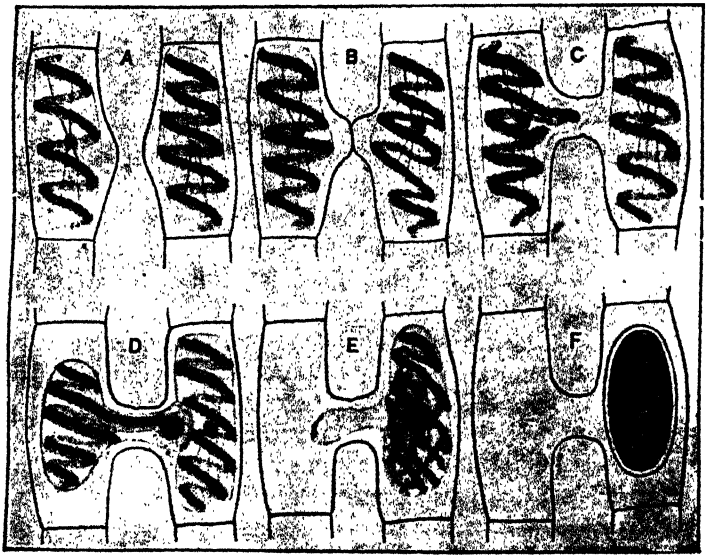


Fig. 16. SPIROGYRA.
Stages in Conjugation.

another, and that they are not liberated as motile structures. This method of sexual reproduction is known as conjugation and the zygote is called a **zygospore.** The zygospore develops a thick protective wall and is eventually liberated from the filament. This generally occurs late in the season, or is induced by adverse conditions; consequently the zygospore falls to the bottom of the water and there rests for a period, until conditions

again become favourable for rapid growth and it germinates.

When the zygospore germinates, the first division is reduction division, so that the original number of chromosomes is restored.

The cell which remains in the uncracked part of the spore wall remains colourless, while the other develops the characteristic chloroplast and general form and then divides to make the new green filament (Fig. 17). The colourless cell contains stored food from the spore not used completely by the first few germination changes. It remains attached to the young filament until this food is used, when both it and the spore wall drop off.

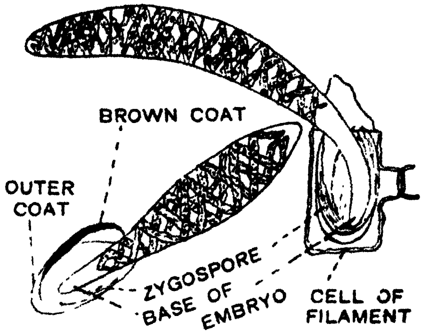


Fig. 17. SPIROGYRA.
Germination of Zygospore.

3. FUCUS

One of the commonest objects on the seashore is brown seaweed belonging to the **genus** Fucus, which is found growing attached to stones, breakwaters, etc. It consists of an attaching disc or haptere and a flat, branched, ribbon-like portion known as a **thallus** (Fig. 18).

The plants are not all quite alike; for some have air bladders along the thallus and swollen tips, these are the common Bladder Wrack; while in others the thallus has no conspicuously swollen parts. The former is known as *Fucus vesiculosus* and the latter as *Fucus serratus*, which is the larger one usually found. These two plants have

so many characters in common that they have been given the same generic name, viz. Fucus. This corresponds in some ways with a surname which is shared by many

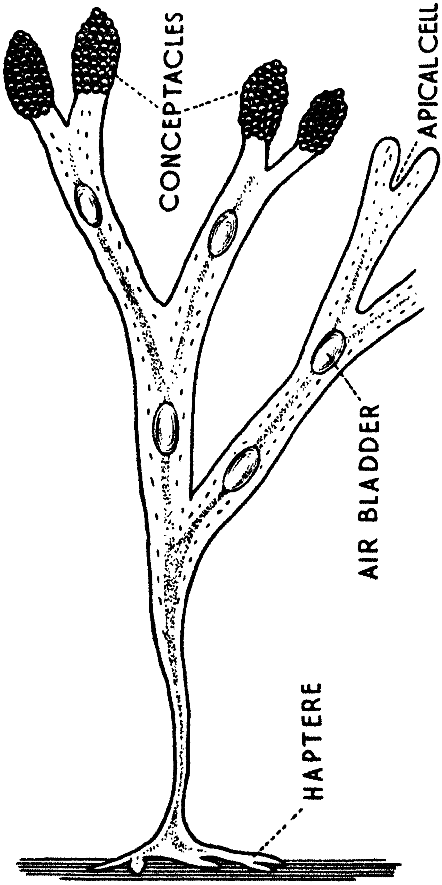


Fig. 18. Fucus Vesiculosus.

individuals. The second name given to the seaweeds tells us the particular **species** of Fucus to which the plant belongs, and denotes that it has certain special characters which

separate it from its very near relations. The two mentioned are the most common on our shores, but further investigation will reveal others.

At the tips a very large number of dots can be both seen and felt. This is where the reproductive organs are produced.

The branching of Fucus is very regular, two equal branches being formed each time. The growing-point is one special cell situated in the depression which occurs very near each tip (Fig. 18). This one cell is known as the **apical cell,** and from it all the cells of the thallus arise by cell division. It has three almost triangular faces, the outer edge, the base of the triangle, being slightly curved. The new cells are cut off parallel to the straight edges of the triangle, chiefly on two sides, the thallus being flat.

To discover the cells of Fucus it is necessary **to cut a section.** For this a very sharp razor is necessary, preferably an old-fashioned razor with a handle and the blade hollow ground on one side only. Safety razor blades can be used, but they should be suitably mounted. The material should be held firmly between the first finger and thumb, and care should be taken to keep all the knuckles straight. The finger should be held so that the razor can rest upon it, whilst the tip of the thumb must be a little lower down so that it is not cut. Then some very thin slices of the specimen should be cut across at right angles to the length of the thallus. It is important to keep the material as wet as possible all the time, so that air bubbles do not collect.

A good many sections should be cut and then floated out in water in a watch glass. The thinnest sections should then be selected and mounted in water if the seaweed is fresh, or in dilute glycerin (fifty per cent. glycerin and fifty per cent. water) if it has been preserved in methylated spirit. If difficulty is experienced in cutting sections of Fucus thallus, it may be found much easier if a sandwich

is made with it and two pieces of elder pith or carrot, and sections are then cut right across the three pieces of material.

On examination of the section, it will be seen to consist of a large number of cells, each containing protoplasm and a number of small brown chromoplasts, which make it very difficult to see the nucleus. The cell wall is very

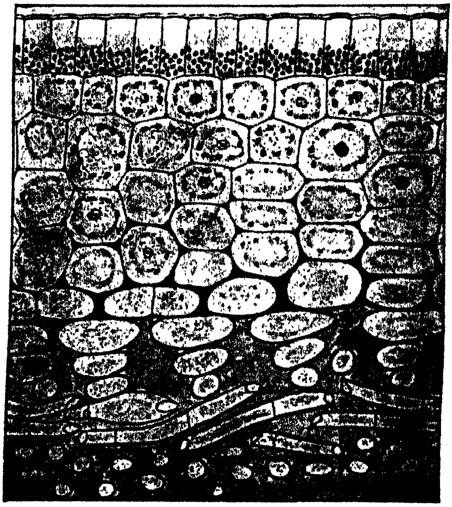


Fig. 19. Fucus.
Part of a Transverse Section of the Thallus.

bright in appearance, and wide; this is due to its mucilaginous nature (Fig. 19). The cells are arranged to make a compact layer on the outside to form the skin or **epidermis.** Next to this there are several layers of cells rather larger than those of the epidermis, but still compactly arranged, making the **cortex.** In the centre the cells are rather a different shape and much more loosely placed; this portion is spoken of as the **medulla.**

It has been noticed that Fucus is brown in colour. If some quite fresh seaweed be obtained and placed in fresh water, the brown colour will dissolve out and the seaweed will then be green owing to the presence of **chlorophyll.** Hence the little coloured bodies in the cells contain two pigments, chlorophyll and the brown one, **fucoxanthin**; consequently they are called **chromoplasts,** not chloroplasts. The brown colour assists the chlorophyll in its work of absorbing light and serves as a protection to it, since

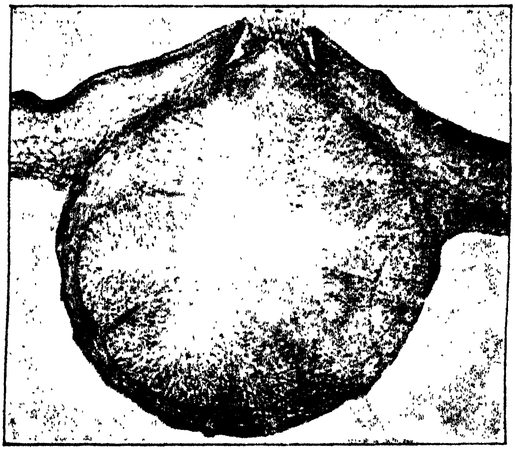


Fig. 20. Fucus.
Transverse Section of a Male Conceptacle.

sometimes it is submerged in the sea and at other times, when the tide is down, the sun shines directly upon it. Fucus, in building up its food, produces a special carbohydrate, known as **fucosan,** instead of the more usual one, starch.

Fucus grows to form quite a large thallus vegetatively, but it only has one method of **reproduction,** namely **sexual.** The specialisation of the tips of the branches has already been noticed, and sections should be cut across some of

these. It will then be seen that the dots are spherical cavities in the thallus, known as **conceptacles,** in which the male and female organs are produced (Fig. 20). It is characteristic of the majority of species of Fucus, that one

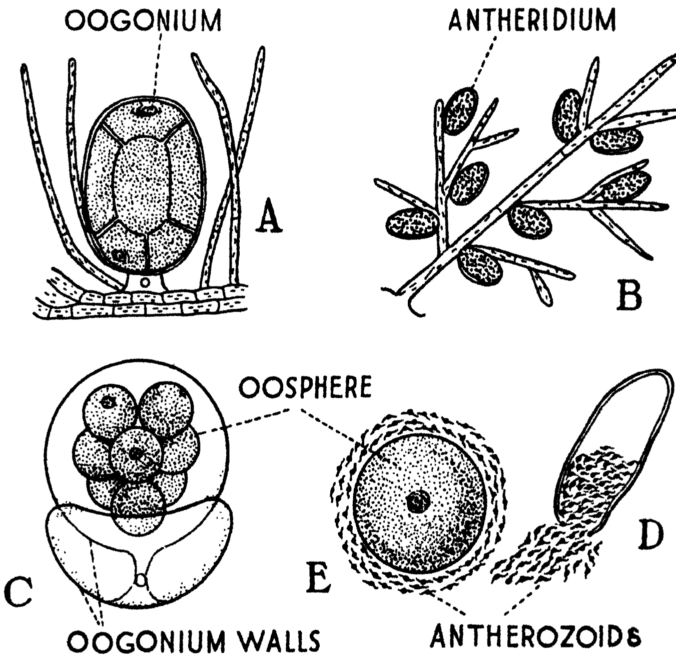


Fig. 21. Reproductive Organs of Fucus.

A, Oogonium attached to conceptacle; B, Antheridia on branched hair; C, Oogonium has burst to liberate the 8 oospheres; D, Burst antheridium; E, Antherozoids swarming round oosphere. [D and E are more highly magnified.]

plant is male and another plant is female. In the case of the male, the conceptacles are filled with very much branched hairs, each bearing several small, brown, ovoid cases, known as **antheridia,** in which the male gametes, or **antherozoids,** are produced (Fig. 21). Each antheridium

begins as one cell, from which a small cell is cut off producing a little stalk. The remaining cell undergoes reduction division and a number of cells are produced, from each of which a biciliate male gamete will be liberated.

The female gametes are produced in **oogonia**, also formed in conceptacles. With the oogonia are a number of slender, straight hairs. Each oogonium also develops a little stalk cell and reduction division occurs. Within the wall of the oogonium cell eight green, spherical **oospheres** are produced (Fig. 21), each consisting of a nucleus, protoplasm, and plasmatic membrane. On the surface of the conceptacle there is a small hole through which the oogonia or antheridia are liberated. This occurs at low tide, the hairs swelling up and forming a lot of mucilage which exudes, bringing the oogonia or antheridia with it.

If fresh seaweed can be gathered at this time and hung up, orange mucilaginous material will be seen to emerge from the male plants, and green from the female plants, containing in each case the reproductive bodies.

When liberated into the sea as the tide comes in, the oogonium wall breaks, the two layers composing it make a little boat, in which for a time the oospheres remain (Fig. 21). Similarly the antherozoids are liberated; these, however, swim about. Later the oospheres are quite free from their case and a large number of antherozoids are attracted to each one at high tide. They apply themselves to the female gamete with their cilia pointing outwards (Fig. 21), so that, by their movement, this non-motile cell is also revolved. After about fifteen minutes revolution one male gamete turns round, and with its cilia forward enters the oosphere. This is the signal for the others to retire. An **oospore** now develops which sinks until it reaches a solid substance to which it can adhere. It does not form a thick protective coat and rest; the constancy of the environment does not seem to demand that. The surface almost immediately begins to spread out to make an attaching

portion. The free part divides, very soon forming an apical cell which produces a small, but typical, new Fucus plant.

All the plants that have been considered so far are very simple in form and yet possess chlorophyll. They belong to a group of plants called **Algae**.

4. HYDRA

If some pond water, containing a few water plants, be placed in a glass vessel and left in a light place for a time, probably a number of short threads, green, white, or brown in colour, will be seen with one end attached to the glass. These can easily be examined with a hand lens in this position. They are species of Hydra. The body of this little animal is cylindrical, and from the free end a number of finer threads, which are called **tentacles**, project into the water (Fig. 22). The tentacles are sensitive to contact, and contract if touched (Fig. 22, B), as also may the main thread. The tentacles are active in catching food for the Hydra. If a small water-animal comes in contact with the tentacles it may fall down apparently stunned, or it may remain attached to the tentacle while this conveys it to the body of the Hydra. Occasionally Hydra may be seen changing its position, which it does by turning "head over heels," this being a further use of the tentacles. Generally Hydra remains in a fixed position by means of its flat basal **foot.** This stationary condition is much more usual in plants than in animals,

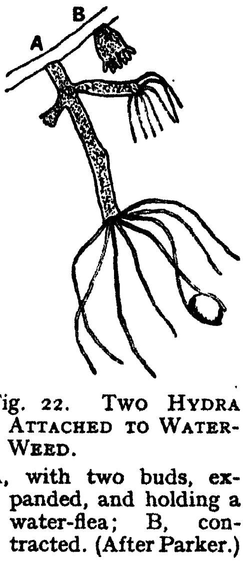


Fig. 22. Two Hydra Attached to Water-Weed.

A, with two buds, expanded, and holding a water-flea; B, contracted. (After Parker.)

as also is the habit of branching which occurs in this animal. Both these habits are, however, known to occur extensively in animals, *e.g.* the well-known Corals and Sponges.

Microscopic examination shows that the body of Hydra is a hollow cylinder; the tentacles are also hollow and surround a little raised cone, called a **hypostome,** at the apex of which is an opening, the **mouth** (Fig. 23). The

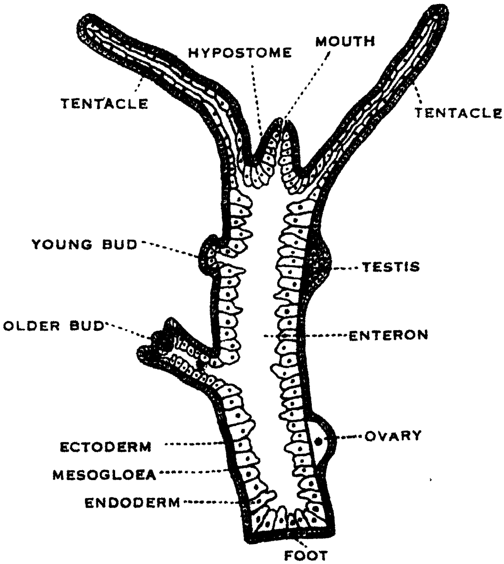


Fig. 23. Median Longitudinal Section of Hydra. (Rather diagrammatic.)

whole body including the tentacles is composed of many cells, which are arranged in two very definite layers, the outer being called the **ectoderm,** and the inner the **endoderm.** The cavity in the middle of the animal is the digestive cavity, or **enteron.** Between the two layers of cells is a gelatinous substance which is very elastic and is called the **mesoglea.**

The ectoderm is composed of several kinds of cells. The most conspicuous of these are conical in shape, with their broad end pointing outwards, making a continuous covering to the body (Fig. 24). At the inner end are one or more contractile processes which run lengthwise in the mesoglea. They are called **muscle-tail-cells**, and when the contractile processes shorten the animal becomes very short and wide (Fig. 22, B). These cells in the foot region contain granules,

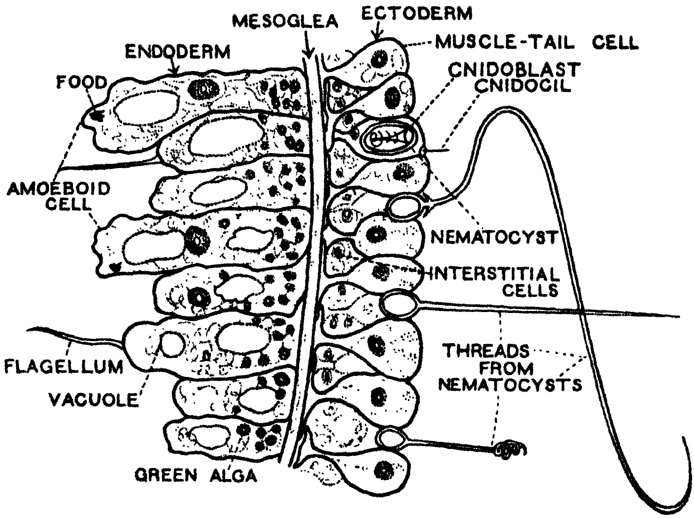


Fig. 24. HYDRA.
A small piece of section through the body-wall (much enlarged).

secreted by the protoplasm, which help the animal to adhere. They all have a conspicuous oval nucleus.

Filling in the spaces between the muscle-tail-cells are small, rounded cells, known as **interstitial cells.** These are a kind of reserve cell, which, should occasion need, can reproduce any of the other body cells. In addition to these cells there are others, known as **cnidoblasts,** which are specially numerous in the ectoderm of the tentacles, where

they occur in groups. Each cnidoblast is a pear-shaped body, with its pointed end directed outwards, and from this there projects a fine, stiff, hair-like, protoplasmic process called the **cnidocil.** On the outer side of the cnidoblast there is also a pear-shaped sac, the **nematocyst,** in which there is a lining of protoplasm, a fluid, and a long, hollow, coiled thread, which arises from its pointed end. When a cnidocil is touched, the protoplasm in the nematocysts is stimulated to contract. This squeezes the sac and the pressure upon the fluid inside causes the ejection of the thread (Fig. 24).

There are three kinds of nematocysts. First, a large kind which ejects a straight thread and has barbs at the base. These are active in catching the animal's food, and may also be organs of defence. When these nematocysts are discharged, their barbs emerge first and wound the prey, then the thread pierces it and the fluid, which is injected, has a temporary numbing effect upon such creatures as water fleas. There are also smaller, barbless nematocysts, some with a spiral thread which twists round the prey, and others with a straight thread, which are of use in attaching the Hydra to its prey or other objects. Nematocysts are continually being renewed by the interstitial cells. In addition to all these there are, scattered throughout the ectoderm, special branched **nerve cells** which are in contact with the cnidoblasts and muscle-tail-cells. These nerve cells are much branched in outline, having thin protoplasmic branches; they have large nuclei and are very sensitive to stimuli, which they transmit and thus cause reactions to take place.

The cells of the endoderm are mostly larger than those of the ectoderm and possess a large vacuole (Fig. 24). The part of each cell next the mesoglea is extended into a small muscle-tail, which runs round the body instead of along it, as do those of the ectoderm. When the animal's body is long and narrow these are contracted. The combined

action of the two sets of muscle-tails enables Hydra to expand and contract its body. The surface of an endoderm cell next the enteron is either amoeboid, or it bears a **flagellum**, which is long and threadlike, somewhat intermediate between a pseudopodium and a cilium. These cells are actively concerned with the nutrition of the animal. The pseudopodia can surround small particles of food like Amoeba does. In addition to this they actively secrete fluids, known as **enzymes**, which help to render the materials soluble, that is, to digest them. The endoderm cells of the hypostome are particularly active in this work of secretion.

The **food** of Hydra consists of microscopic plants and animals which are taken in, through the mouth, with the water, as well as larger creatures which are caught by the tentacles. The latter are only stimulated by organic objects, not by materials which could not serve as food. There are no special excretory organs. Food which remains undissolved in the enteron is ejected from the mouth by a sudden contraction of the body. Food which is dissolved in the enteron, as well as the substances taken in by the pseudopodia, nourish the endoderm cells, and from these cells nourishment passes in solution to the ectoderm. Probably liquid waste material is given off from the body surface generally. Similarly **respiration** also takes place from the entire surface of the animal.

Hydra reproduces itself freely under favourable conditions by a process known as **budding** or **gemmation** (Fig. 23). This process resembles in many ways the formation of a branch in a plant. The ectoderm and endoderm in a particular spot grow rapidly, forming a small swelling, into which there is a projection of the enteron. On its free end this bud develops tentacles and gradually becomes independent of its parent from which it will eventually be detached. Several buds may occur on one Hydra at the same time, so that multiplication by this method

may be very rapid. Hydra may occasionally reproduce by fission into two. It can also replace parts which may be accidentally lost. This latter process is known as **regeneration,** and this little animal can make very great use of it.

This animal, like others, finds that *sexual reproduction* is necessary at intervals. Each animal in the summer, bears both male and female organs, that is, is hermaphrodite. These organs arise by rapid multiplication of the interstitial cells causing protuberances, of which that nearest the foot becomes an **ovary** containing the female gamete, while the others become **testes** containing male gametes. In the development of the ovary one of the interstitial cells, which is destined to form the female gamete, or **ovum** (consequently known as an **oocyte**), becomes amoeboid and increases considerably in size by feeding on the others. The oocyte also collects in its protoplasm numerous dark, spherical granules of food, known as yolk. Later it becomes spherical and a gelatinous coat develops round it.

At this stage reduction division occurs, and here, as is usual in **oogenesis,** or the formation of an ovum, the process is accompanied by the unequal division of the cytoplasm. The oocyte nucleus divides by meiosis, but one large cell is formed and one small one. The latter is known as the **first polar body.** At the second division the polar body forms two small cells and the large cell forms one large one, the ovum, and one small one, known as the **second polar body.** Thus the oocyte forms one ovum and three cells which disappear not four ova as might be expected from reduction division.

Now that the ovum is developed the layer of ectoderm cells which covered it shrink back, so that it is exposed to the water and can receive a male gamete. At this stage it is about a millimetre in diameter and quite conspicuous on the body of the Hydra. Meanwhile the cells in the testes

have multiplied and become **spermatocytes,** that is the cells which, by meiosis, will each produce four **spermatozoa.** Each spermatozoon has a conical head, containing the nucleus and most of the cytoplasm, a neck, and a tail by means of which it swims in the water, when the covering layer of the testis has been broken.

As the ovary and testes are not usually mature together on the same animal, **cross fertilisation** generally occurs, that is, the ovum of one Hydra becomes united with the spermatozoon from another Hydra, to form the **zygote.** The zygote undergoes division, forming a number of cells, which form a hollow sphere. This is called a **blastula** or **blastosphere.** The single layer of cells divides to form two layers, then follows the differentiation of the body parts and cells to form the new Hydra. A thick, spiny, protective covering of a horny substance develops round the blastosphere, in which stage it falls from the parent and rests for several weeks, during which it may be carried by movement of the water and animals to a new home. Animals with bodies resembling those of Hydra are called **Polyps.**

The colouring matter of Hydra is found in the endoderm cells. **Hydra viridis** is characterised by being green, due to the presence of a green alga in the endoderm cells. The colour is therefore due to chlorophyll. The plant and animal live together quite happily, forming a little community in which both give and both receive. Such an arrangement is spoken of as **symbiosis** (*sym*—together: *bios*—life). The alga is able to use the sunlight and carbon dioxide, and to build up carbohydrates because it has chlorophyll. Consequently the Hydra gets an abundant supply of these. It also benefits by liberation of oxygen from the alga. The alga benefits by the carbon dioxide breathed out by the animal, and by the abundant nitrogenous material which enters the enteron in the solid food secured by the Hydra. **Hydra viridis** is never found without its alga because it enters the oocyte.

5. OBELIA

If the buds produced on Hydra as reproductive bodies did not separate from the parent, but remained attached, a colony would be formed. This is what has occurred in Obelia (Fig. 25). Such animals are known as **hydroids.** Obelia is commonly found growing upon seaweeds near low-water mark. It consists of an attaching portion, or **hydrorhiza**; an upright stem about an inch long, the **hydrocaulus**; and a number of lateral members or **zooids,** the heads of which are called **hydranths.** This is a colony, or gemmarium, of polyps, which have remained joined together to make the stem portion, and in which they are all joined to make one continuous whole. The entire colony is enclosed in a cuticular secretion of the ectoderm, which forms a horny covering known as the **perisarc,** surrounding the living matter, the **coenosarc.** There is a distinct space between the perisarc and the ectoderm except at intervals where special processes join across. The perisarc expands at the base of each hydranth to form a cup or **hydrotheca** into which the hydranth can be withdrawn.

The structure of Obelia closely resembles that of Hydra. The tentacles are more numerous and have a solid core of large endoderm cells, with a very stout covering of intercellular substance. They contain large vacuoles in their cytoplasm.

When the colony is fully developed special bodies known as **blastozoids** are formed, by budding, in the axils of the zooids. They are narrow, cylindrical tubes, with neither mouth nor tentacles. The special cups of the perisarc, which contain them, and end in a small hole, are **gonothecae.** From the blastozoid a number of lateral buds are formed, which develop into **medusae,** or small jelly-fish.

The medusa, about ¼ in. in diameter when fully grown, consists of a circular bell-like disc, the umbrella (Fig. 26).

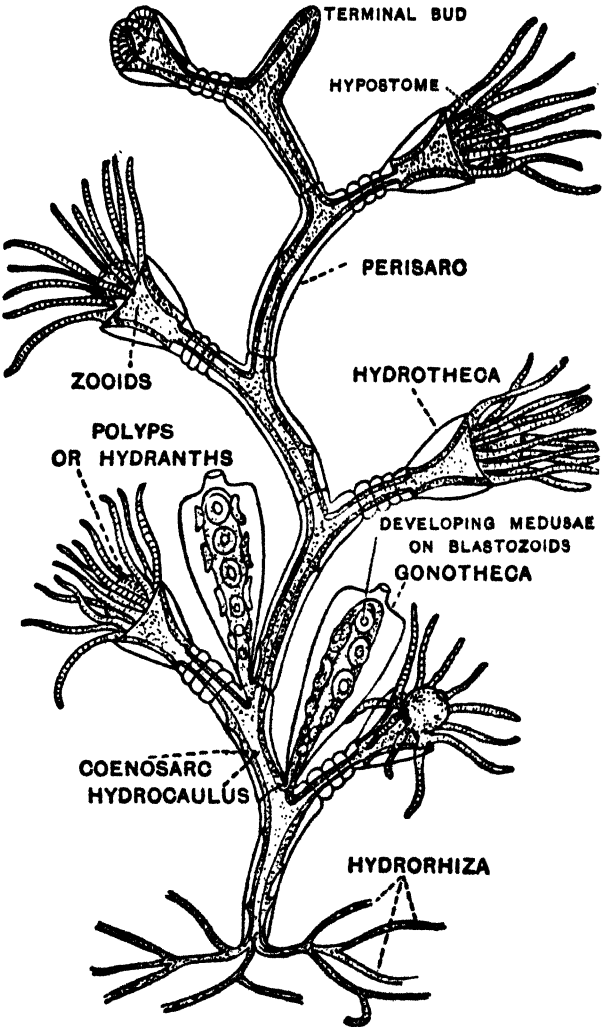


Fig. 25. A GEMMARIUM OF OBELIA GENICULATA [MAGNIFIED].

From the centre of the concave surface hangs a short, hollow process, which terminates in the mouth. This is the **manubrium**, and its cavity is continuous with a central cavity in the umbrella, from which four radiating canals lead into a circular one round its margin. The whole of this cavity, which is concerned with the digestion of food like the enteron of Hydra, but is more complicated in

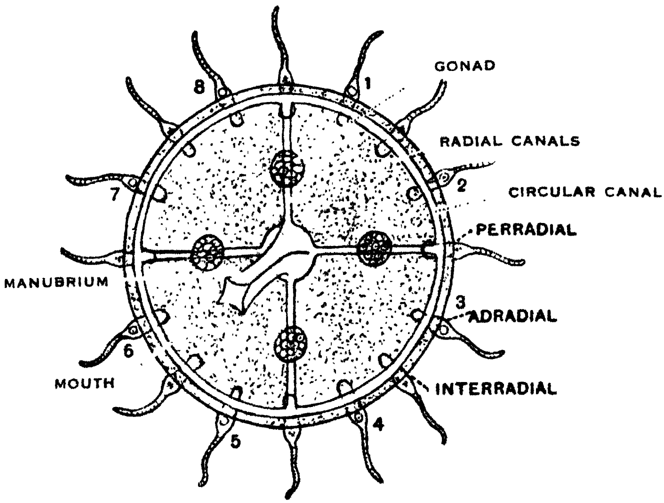


Fig. 26. MEDUSA OF OBELIA SEEN FROM THE VENTRAL OR ORAL SIDE.

The figures 1 to 8 are placed near the bases of the adradial tentacles containing the statocysts. The gonads are seen on the radial canals and the manubrium in the centre. The number of tentacles is reduced.

form, is called the **coelenteron**. The coelenteron is everywhere surrounded by endoderm between which and the ectoderm is mesoglea (Fig. 27). The double layer of endoderm between the radial canals is called the **endoderm lamella**. The margin of the umbrella is fringed with tentacles, which increase in number as the medusa gets older. The tentacles situated at the ends of the radial

canals are spoken of as per-radial; midway between these are four inter-radial tentacles, and midway between these again are eight called ad-radial. Their bases are swollen and on the under side a few ectoderm cells are pigmented, forming spots specially sensitive to light. The eight ad-radial tentacles produce small vesicles from the ectoderm on the inner side, containing calcareous matter, which are called statocysts, because they are organs of equilibrium.

The development of a medusa on the blastozoid is shown in Fig. 28. A small projection occurs in the central cavity

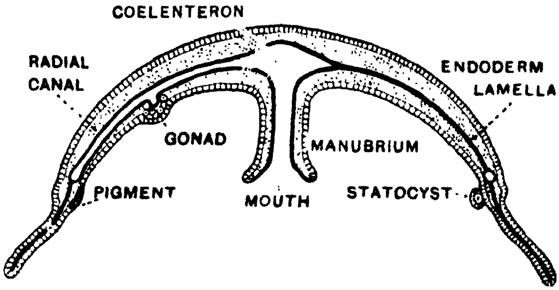


Fig. 27. DIAGRAM OF A VERTICAL SECTION OF A MEDUSA.

The endoderm is represented by a black line, the ectoderm by a band of transverse lines, the mesoglea by dots. The section really consists of two separate halves, that on the left passing through a radial canal, that on the right through the endoderm lamella between the canals.

forming a vesicle surrounded by endoderm, mesoglea, and ectoderm. The cavity grows and gradually assumes the umbrella shape of the medusa; then the ectoderm farthest away from the blastozoid separates into two layers. The inner layer acquires a cavity and enlarges and becomes the sub-umbrella with the manubrium in its centre. The membrane, which at first closes round from the margin of the umbrella, breaks, forming a circular shelf projecting from the margin and called the velum. In Obelia after a time this disappears

Each medusa produces four reproductive organs or gonads. One produces four testes, another produces four ovaries. These are formed ventrally from the ectoderm beneath the canals, and resemble those of Hydra.

The fertilised ovum segments to form a hollow blastula. This becomes solid. Then the outer cells develop cilia

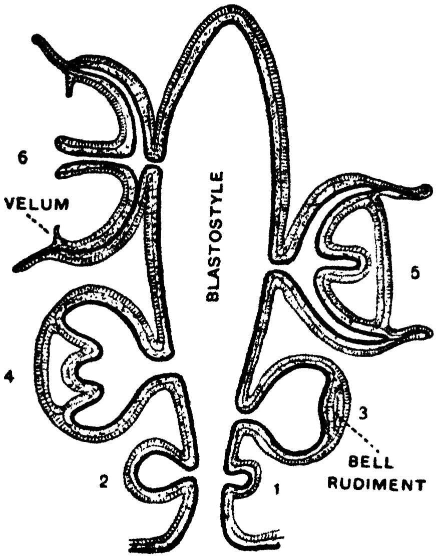


Fig. 28. Diagram of the Development of a Medusa from the Blastozoid.

The successive stages are numbered 1 to 6 and are represented as all connected with the same blastozoid.

and the embryo is then called a **planula.** A cavity develops by splitting of the solid endoderm; and subsequently the form is converted to that of a zooid, which attaches itself by one end to a solid body, and forms a mouth by rupturing the other end. A circle of tentacles then develops below the mouth. By budding or gemmation the hydroid gemmarium is again produced.

This animal shows during its life a very regular cycle of changes, which are sometimes spoken of as **alternation of generations**, there being a regular alternation of hydroids and medusae. More strictly it is an alternation of gemmation, in which many asexual reproductions occur, and of one sexual reproduction. Further, in the former the new organism is derived from tissues rather than one cell. To this series of changes the term **metagenesis** has been given.

Obelia is an animal which changes its form in different stages of its life history. There is the medusa, which is either male or female, and the hydroid. In the latter the blastozoids are quite different from the zooids. Such changes of form and structure in the same organism are spoken of as **polymorphism**.

CHAPTER IV

TWO SIMPLE LAND PLANTS

1. PELLIA

This plant forms green masses up the sides of ditches, streams, and springs, and in similar moist situations. Each plant is a thin, flat, green body called a **thallus** (Fig. 29), branched to form many lobes, thus reminding us somewhat of the liver of an animal, such as rabbit, and giving the plant the name **liverwort.** There are many liverworts, differing from one another in details of form and structure, Pellia being one of the commonest and simplest. The plant is rather thicker in the centre and attached to this central part, on the ventral surface, are a number of hair-like structures which penetrate slightly into the soil. The thallus branches at its end and forms two similar parts.

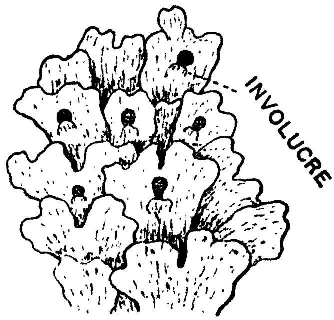


Fig. 29. PELLIA EPIPHYLLA. With young sporogonia still enclosed in the calyptras.

A transverse section taken across the thallus shows that it is made up of a large number of rounded cells in close contact with one another. The section is several layers deep in the centre, but thins out to become only one cell deep at the two edges. In the centre part some of the cells in the outermost layer on the ventral surface are elongated to form the hairs already noticed (Fig. 30). These are called **rhizoids.** Apart from the rhizoids the cells are all very similar to one another. Each has a cellulose wall, protoplasm, numerous small, oval, green

chloroplasts, a nucleus and a central vacuole containing cell sap. Those nearer the dorsal surface may have rather more chloroplasts. At the tip of each branch is a two-sided cell called the **apical cell.** This cuts off new cells mainly on two sides, and hence the thallus is flat. When it branches there are always two equal branches formed, because the apical cell divides into two equal parts, which behave similarly to one another: this is spoken of as **dichotomous branching.** If a section be taken parallel to the surface and the piece that was ventral mounted, with the lower surface uppermost, the apical cell will be seen to be protected by a number of mucilaginous scales. These, although very small, keep the growing-point damp during dry weather, so that, although the rest of the thallus may wither, the apical cell can start to grow again when the rain returns.

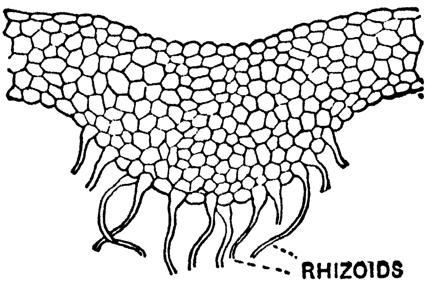


Fig. 30. PELLIA EPIPHYLLA.
Transverse section through a central region of the thallus.

At the end of April or the beginning of May, the thalli develop a number of dots on the central region of the dorsal surface. A little flap is also noticeable just behind the tip (Fig. 31).

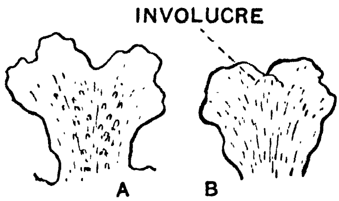


Fig. 31. PELLIA EPIPHYLLA.
Branches of thallus; A, with Antheridia; B, with Archegonia.

A longitudinal section should be taken through the central region of a thallus so that it passes through a flap

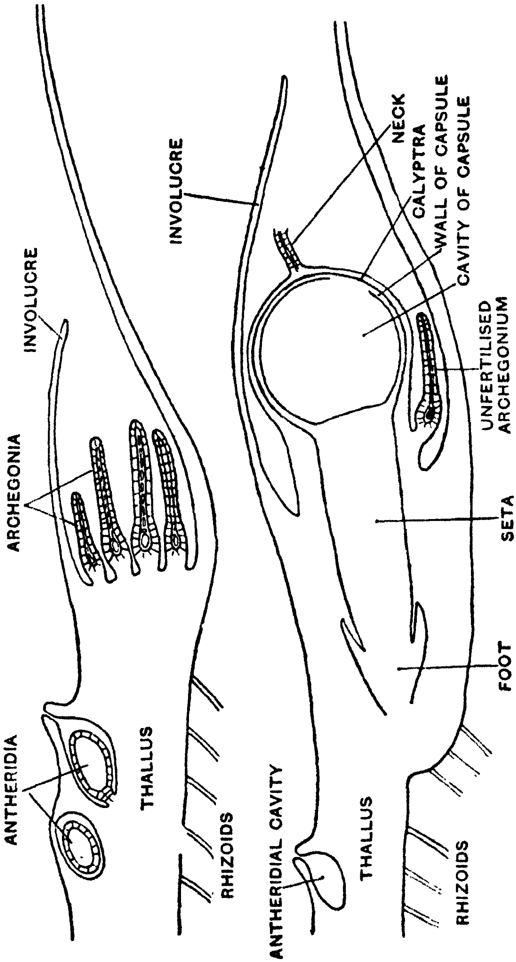


Fig. 32. Pellia Epiphylla.
Longitudinal sections of thallus with Sexual Organs (upper figure), and with ripe Sporogonium (lower figure).

and some of the dots. This reveals that the dots are openings in the thallus leading into cavities, which contain oval-shaped structures (Fig. 32). Each of these has a stalk composed of several cells, and one that has been cut through reveals a wall consisting of a single layer of cells, and inside the wall a number of rounded cells (Fig. 33, A). Each of the latter eventually forms inside it a body consisting of a large coiled nucleus, a very small portion of protoplasm, and two cilia. These become motile and are male gametes (Fig. 33, B). They are known as **antherozoids,** and the case containing them as an **antheridium.** When the antherozoids are ripe the wall of the antheridium breaks, and they escape. On account of the moist situation in which Pellia grows, there is always sufficient water for them to move about in, and this they do by the movement of the cilia.

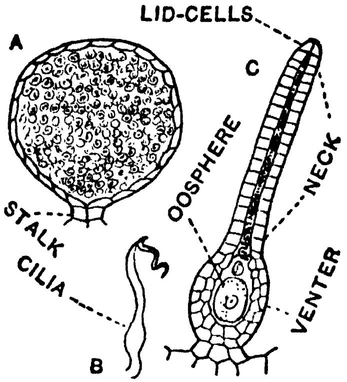


Fig. 33. PELLIA EPIPHYLLA.
A, Antheridium containing Antherozoids; B, an Antherozoid; C, Archegonium.

Under the flap, or involucre, are a number of flask-shaped structures called **archegonia.** These also have a wall composed of a single layer of cells, and each has a multicellular stalk (Fig. 33, C). The rounded part is called the venter, and the elongated part the neck. Inside the venter are two nuclei, each surrounded by protoplasm, so that they are really cells without walls. The larger basal one is the **oosphere,** or female gamete, and the smaller one the ventral canal cell. The neck is filled by a row of cells called neck canal cells, but as the archegonium ripens these

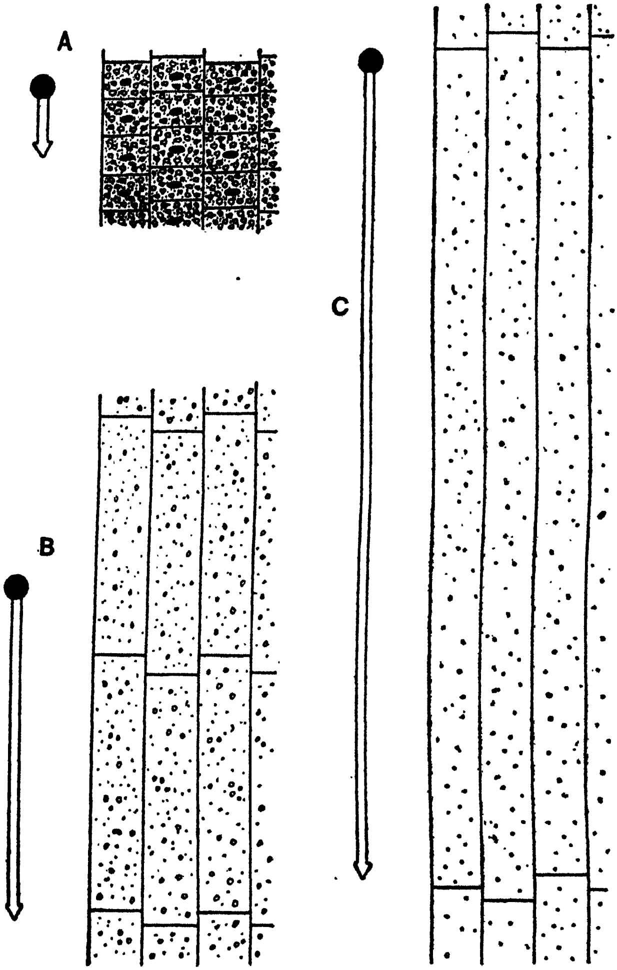


Fig. 34. Pellia Epiphylla.
Elongation of Seta due to growth in length of its cells. A, resting stage; B, C, stages in elongation.
In A, B, and C the entire Sporogonium is shown diagrammatically on the left, and part of the Seta on the right, the magnification being uniform in the three drawings.

disintegrate and form mucilage. This holds a great deal of water which causes it to swell somewhat.

The antherozoids find their way to the archegonia, possibly attracted by some chemical substance. An antherozoid enters the neck of an archegonium, swims through the mucilage, and fuses with the oosphere. Thus **fertilisation** occurs, and the oosphere becomes an **oospore.** Although several oospores may be formed beneath one involucre, only one undergoes further development. Notice that, since two nuclei have fused to produce the oospore, it will possess a nucleus with twice the number of chromosomes of the nuclei in the thallus cells.

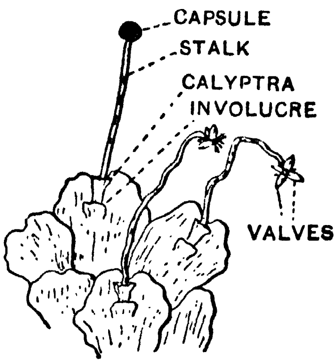


Fig. 35. Pellia Epiphylla with Ripe Sporogonia.
(Two of them have shed their spores.)

In January and February tiny, round, dark-coloured objects can be seen beneath the involucre. These have developed from the oospore, and a longitudinal section shows their structure (Fig. 32). The round object, the **capsule,** is on a short, multicellular stalk, the **seta,** and there is a mass of tissue called the **foot** embedded in the thallus. The round top has a wall consisting of two layers of cells and contains numerous round cells. It is covered by the **calyptra,** which is the remains of the neck and venter of the archegonium inside which it developed. This whole structure is sometimes called the sporogonium.

In the spring the seta elongates rapidly, owing to the enormous increase in size of the cells composing it (Fig. 34). This carries the capsule up above the thallus (Fig. 35). By this time the capsule contains a number of oval-shaped

bodies and also some long, narrow cells called **elaters,** which have on them two spiral bands of thickening. Some of these elaters are attached to the base of the capsule, while others are free (Fig. 36). The oval-shaped bodies are **spores,** and were formed from cells in the capsule, called spore mother cells, which divided by reduction division so that each one formed four spores. The nucleus of the spores would therefore differ from that of the original cell by containing only half the number of chromosomes. As all the capsule cells have originated from the oospore, they contain a double number of chromosomes, but the reduction division restores in the spores the original number present in the thallus cells. These spores are asexual.

The spores start to germinate in the capsule, so that, at the time of examination, each one probably consists of a small oval plate of cells. Eventually the wall of the capsule splits into four valves, which fall back (Fig. 35), and then the use of the elaters becomes evident. Owing to the thickening on their walls they shorten, if the air is dry, and lengthen if it is wet. These movements cause the spores to be flicked off and gradually dispersed. Moreover they will be cast adrift in dry weather, when they stand some chance of being borne by the air some little distance from the parent plant, so that when they germinate they can colonise some new, and possibly less crowded, spot.

Each spore develops a rhizoid and a small, green, filamentous growth, which very soon develops a characteristic apical cell, from which a new thallus develops. The small preliminary growth is called a **protonema.** The new thallus will bear gametes and later capsules containing more spores. Thus thallus and capsule must follow one another regularly for the continuance of the race. The thallus contains chloroplasts and can therefore manufacture sugar. It can also take in, for food, mineral salts in solution from the soil by means of its rhizoids. Thus the thallus is self-supporting, able to procure the necessary materials,

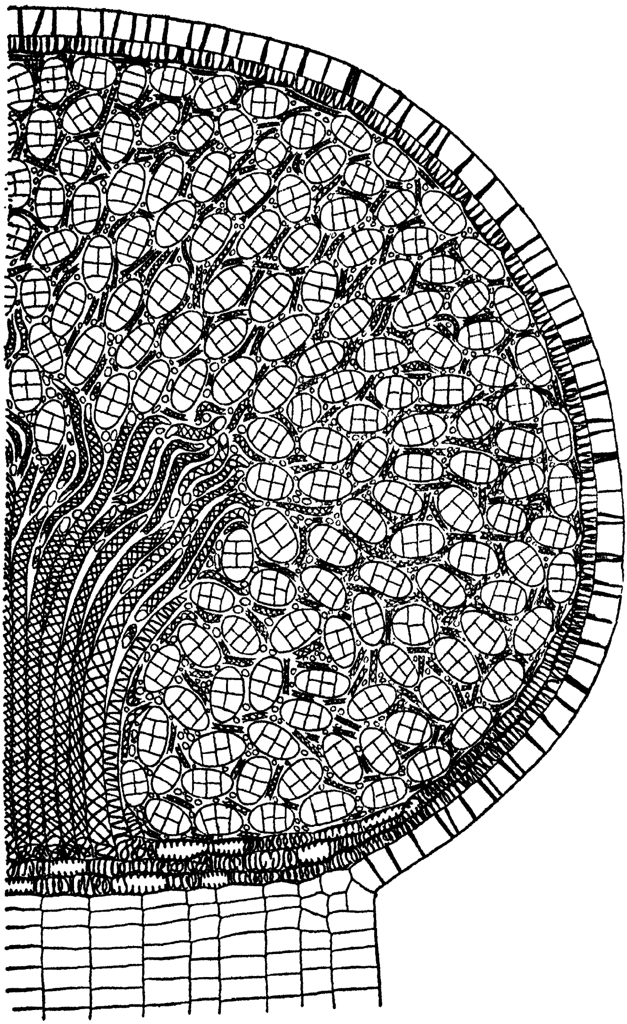
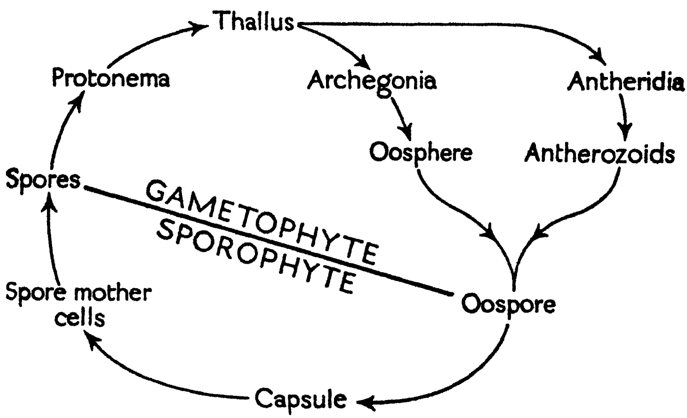


Fig. 36. Pellia.

Part of a Longitudinal Section through ripe Sporogonium, showing half of the Capsule and the uppermost portion of the Seta.

and manufacture its own food. The capsule is obviously entirely dependent on the thallus for the food necessary for its development. The foot passes this food from the thallus to the capsule.

Because the thallus bears the gametes, it is called the **gametophyte** generation, and it is followed by the spore-containing capsule, which is called the **sporophyte** generation. Pellia shows **alternation of generations** because they succeed one another regularly. Notice that all the cells in the capsule, the sporophyte, contain twice the number of chromosomes of those in the gametophyte, until the spores are formed. The life cycle may be represented thus:—



The structure of Pellia thallus is so simple that it can stand nothing in the nature of a drought. It has little means of protecting itself against loss of water, and therefore shrivels almost at once if it cannot obtain sufficient to replace that which it is bound to lose in the form of water vapour. All plants must give off a large amount of water vapour, because they take in their food dissolved in water. Thus Pellia requires much water to live, and also for its fertilisation, since the male gametes must swim

to the female. It is in fact a plant that seems to have just stepped from water on to dry land, obtaining a foothold thereon, but still needing to be almost bathed in water.

2. FUNARIA

The **moss,** known as Funaria, grows on walls and soil where moisture is fairly abundant. Each plant has a stem-like portion, very thin, and reddish-brown in colour. This bears tiny green leaves, and at the base rhizoids, which penetrate the soil (Fig. 37). The leaves are so thin that they may be mounted whole on a slide in order to examine them with the microscope. Each consists mainly of cells containing small, oval chloroplasts. The leaf is slightly thicker in the centre, and here there are some longer cells forming a very simple main vein. The outline, usually called the margin, of the leaf has tiny teeth along it. The cells with chloroplasts manufacture sugar, and the longer cells in the centre part probably mainly conduct it into the stem.

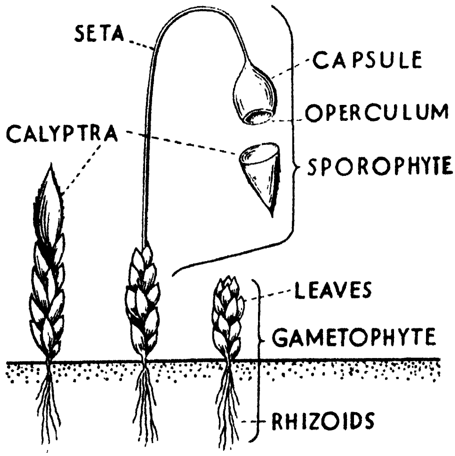


Fig. 37. Funaria Hygrometrica Plants.

A transverse section of the stem (Fig. 38) shows that the cells of which it is composed are not all alike. There is a little central strand composed of tiny cells with very thin walls. It is difficult to cut by hand a longitudinal section of such a tiny stem, but if a prepared one is available these

central cells are seen to be longer than the others. Their very small transverse area helps them to conduct sap by capillarity, their function being to conduct the food in the stem. Hence they are said to form a **conducting strand.** The surrounding cells form the cortex of the stem. The outermost layer of cells form the skin, or epidermis, and their thickened walls prevent the stem from losing too much water vapour. The leaves give off water vapour. The outermost cells of the cortex usually have thick walls.

The rhizoids may be mounted on a slide, and will be found to be multicellular and branched.

During the early summer the leaves at the tip of the plant flatten out, giving a star-like appearance. If thick longitudinal sections are cut and mounted, bodies other than leaves will be found at the tip. The tip may just be spread out on a slide in order to find them. In some cases we find long, oval-shaped bodies on stalks (Fig. 39). These are the male organs, antheridia, and will ultimately contain antherozoids like those of Pellia. There is a special cell in the wall, the cap cell, which splits off to release the antherozoids when ripe.

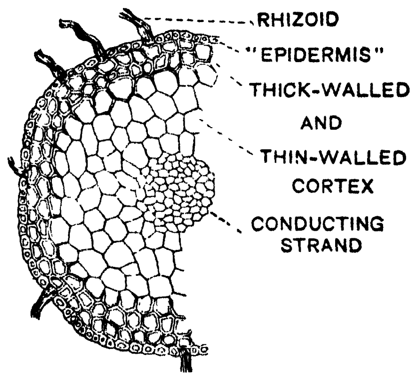


Fig. 38. Stem of a Moss. (Transverse section.)

If the tip of an entirely different plant be examined, the female organs may be found. Plants growing very near to one another are likely to be all male or all female. The reason for this will appear later. Because one plant bears the male organs and an entirely different plant the female

organs, Funaria is said to be **dioecious** (Gr. *di* = twice, *oikos* = a house). The female organs are **archegonia.** They have a slightly larger stalk than those of Pellia, and the top row of neck cells curve away from one another somewhat when the archegonium is ripe. Fertilisation occurs as in Pellia, and an **oospore** is formed.

As a result of the development of the oospore the female plant in due course has a sporogonium, consisting of a

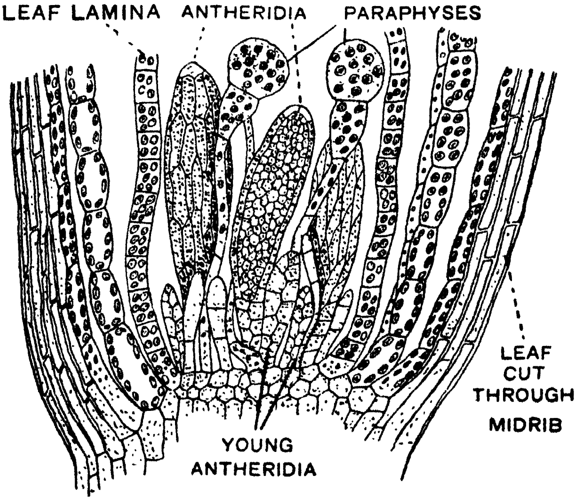


Fig. 39. Apex of Male Shoot of Funaria. (Longitudinal section.)

capsule, a **seta,** and a **foot,** growing from its tip (Fig. 37). At first the capsule is green and has over it a little pointed cap, the **calyptra,** which is the remains of the archegonium. Later the capsule becomes brown and the calyptra can easily be pulled off, revealing the pear-shaped capsule with a little lid, the **operculum,** at one end.

A longitudinal section of a fairly young capsule (Fig. 40*a*) reveals its structure. There is a solid rod consisting of cells in the centre, the **columella.** Forming a cylinder

round this is the **sporesac**, consisting of an inner and outer wall between which are spore mother cells. Surrounding this is a cylindrical air space crossed by rows of cells, called trabeculae. The base of the capsule is solid

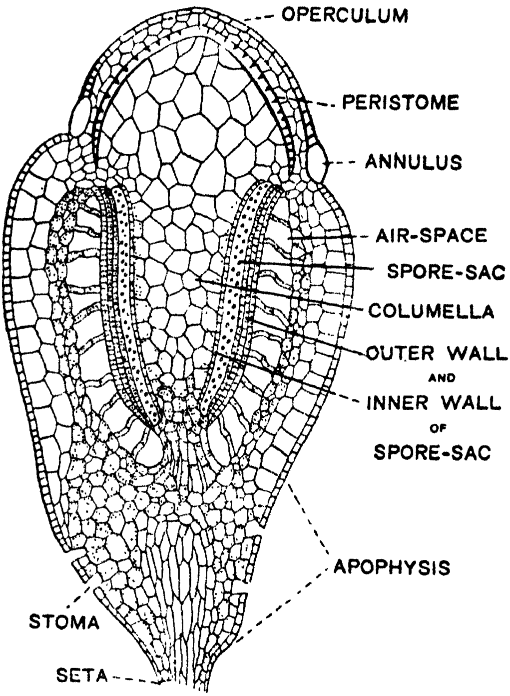


Fig. 40*a*. Capsule of Funaria.
(Longitudinal section.)

and here some cells contain **chloroplasts**, and may be called assimilating tissue, because although it essentially takes its nourishment from the gametophyte, this sporophyte can make its own sugar in these cells. There are special pores in the wall here to facilitate interchange of gases. They are called stomata, and are like those found in

higher plants. The seta has a central conducting strand like the stem.

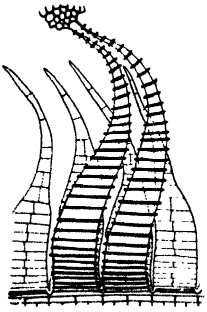


Fig. 40*b*. FUNARIA.
A portion of the Peristome from above, showing two of the outer (exostome) teeth and four of the inner (endostome) teeth.

The spore mother cells form tiny spores in tetrads by reduction division, and when the capsule is ripe it is chiefly a box containing spores. For these to escape the operculum must be shed, and a special row of cells, the **annulus**, at its base brings this about. Some of the annulus cells have thick walls, and when the air is dry these cause a break owing to their contraction. Beneath the operculum, attached to some strong cells, the **rim**, are two rings of sixteen teeth each, constituting the **peristome**. The outer sixteen are reddish and have thick outer walls and transverse walls going about halfway across them. The inner teeth are immediately below the outer, but curve so that their tips are between the tips of the others (Fig. 40*b*). These teeth part in dry weather and close together in wet weather, so that the spores will only escape when it is dry, and they may be wind-dispersed.

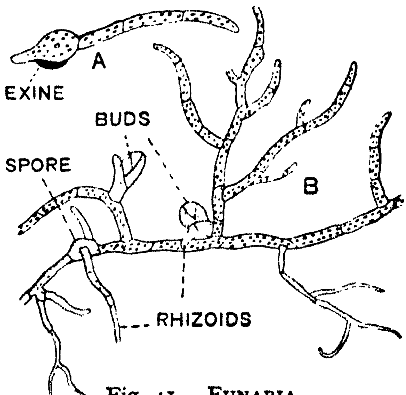


Fig. 41. FUNARIA.
A, Germinating Spore; B, Protonema.

The moss plant bears the gametes and is the gametophyte. The foot, seta, and capsule form the sporophyte. These

two generations must succeed one another as in Pellia, but the spore forms many new gametophytes. A large number of asexual spores are produced in the capsule, thus providing for a large number of new gametophytes. Some gametophytes are male and some female. The male ones produce antherozoids and the female produce one sporophyte as a result of sexual reproduction. When the spore germinates the outer coat, or exine, is burst. The result of its germination is a green, branched filament, like an alga. This has rhizoids arising from it at intervals, and after a time multicellular buds appear (Fig. 41). The structure is called a **protonema,** and every bud will form a moss plant. This is why moss plants always grow in groups, and why a whole batch is liable to be either male or female. The growth of moss plants in little clusters is known as the colonial habit. The life cycle is essentially the same as that of Pellia. Moss plants have assumed the erect habit, and the investigation of different genera of mosses shows that plants of this group have gradually become more and more adapted to live on dry land.

CHAPTER V

THE EARTHWORM

1. EXTERNAL APPEARANCE AND HABITS

One of the most common English earthworms is *Lumbricus herculeus*. During examination a live earthworm must not be allowed to become dry, as this means death to it. It can be kept in a corked glass tube, where the atmosphere is moist. That an earthworm has a head and a tail can be shown by allowing it to crawl over a damp

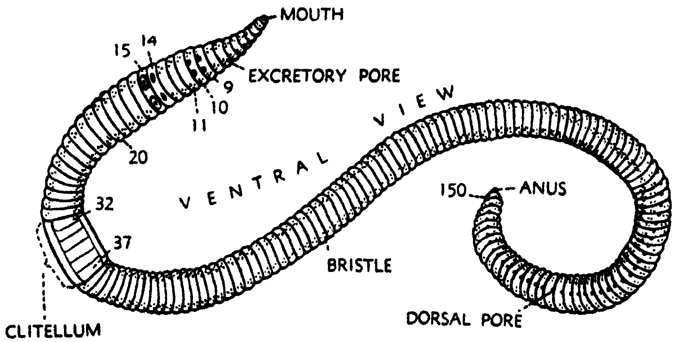


Fig. 42. Earthworm.

Anterior end ventral. Posterior end dorsal.

surface, such as damp blotting-paper, when it will be found that the same end is always forward. This forward or head end is more pointed than the tail. The worm also crawls with the same surface upwards, and this shows that it has a dorsal and a ventral surface, and, consequently, a right and left side. The dorsal surface is darker than the ventral, and a bluish-red line traverses its length.

The long, thin body is divided into segments, the average number of these being about 150. Beyond the first segment a kind of lip, the **prostomium**, overhangs the mouth which is on the ventral surface. An obvious external feature of an adult earthworm is a ring-like band occurring from segments 32 to 37. Its ends do not quite meet on the dorsal surface, and it is rather like a saddle placed over the body. It is called a **clitellum.**

By the use of a lens, openings can be distinguished on the worm's body in addition to the mouth and the **anus,** that is, the opening of the other end of the digestive tract at the extreme posterior end of the body. The largest and most obvious apertures are a pair with swollen edges, occurring ventrally in segment 15. Through these the male gametes are shed. Immediately in front of them, in segment 14, are a smaller pair through which the female gametes emerge. Between segments 10 and 11 and 10 and 9 on the ventral surface, are two pairs of small openings called **spermothecal apertures,** which we shall mention again later. On the ventral surface of every segment except the first three and the last, a minute pair of **nephridiopores** open and through them the waste material formed in the worm's body is discharged. In each of the grooves between the segments, starting posterior to the eighth, there is a dorsal pore. Through these is discharged a fluid which keeps the body surface moist. It is helped in this by some more fluid secreted by glands in the skin.

A worm, stroked from tail to head, feels rough to the fingers. A piece of worm's skin mounted and examined under the microscope reveals four pair of bristles on each segment (Fig. 43). These are stiff and point backwards, and are responsible for the roughness felt on stroking the worm. If the worm be allowed to crawl over some paper, the scratching of these bristles is audible. They answer the purpose of limbs, since they enable the worm to move forward, and are called **chaetae.** The worm

stretches out the front part of its body, fastens it to the soil by means of the chaetae, and then draws up the hind part.

The earthworm inhabits the soil in which it makes burrows, partly by boring, and partly by swallowing the soil. The opening of the burrow is usually closed by small stones, or leaves, pulled into it by the narrow end. Plenty of earthworms can be seen during a walk round the garden after dark with a light. At night they stretch out of their burrows, usually keeping in the posterior end of their body. The earthworm has no ears, but it feels vibrations very readily, and anything which causes vibrations in the ground causes the earthworms to withdraw into their burrows. If the weather is very dry or frosty the worm burrows deeper.

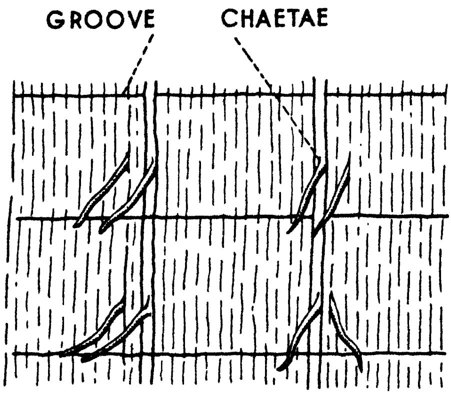


Fig. 43. SURFACE VIEW OF SKIN FROM ONE SIDE OF EARTHWORM. (Examined microscopically.)

Soil always contains a certain amount of organic material, and this constitutes the food of the worm; but most of the soil it swallows contains no nutriment, and is therefore ejected from the anus as waste material. This soil, which has become finely powdered, is often visible as worm casts.

Thus, so far as the soil is concerned, the earthworm aerates it by burrowing, and digs it by bringing the deeper soil to the surface as worm casts. In this way worms help the gardener. Charles Darwin, experimenting in his

garden at Downe, calculated that worms bring up every year enough soil to form a layer one-fifth of an inch thick on the surface.

2. DIGESTIVE AND EXCRETORY SYSTEMS

To investigate these, lay a worm on its ventral surface on some paraffin wax, or a layer of sheet cork, stuck into a pie-dish. Stretch out the body and put a pin into the first and last segments. With a pair of scissors cut through the body wall along the mid-dorsal line from about segment 30 to the anterior end of the worm. The segments visible externally are separated from one another by thin partitions called **septa.** Cut these and pin back the skin on either side (Fig. 44). These septa do not extend completely across the body. Running down the centre of the body is a tube, the digestive tract or alimentary canal. The cavity inside this tube corresponds to the enteron of hydra, since within it food is digested. The inner wall of the alimentary canal corresponds to the endoderm and the body wall to the ectoderm of hydra. Whereas in hydra there is only a layer of jelly between these two, in earthworm there is a new cellular layer, the mesoderm, enclosing the body cavity or **coelom,** in which lie organs of reproduction and excretion, and blood vessels, all formed from the mesoderm.

The mouth cavity occupies segments 1 and 2 of the worm's body. Between segments 2 and 3 the canal narrows, and then widens again into a rounded part called the **pharynx,** extending as far as the end of segment 6. The pharynx is connected to the body wall by strands of muscle. Movements of this cause contraction and expansion of the pharynx so that food is sucked into it. The alimentary canal is then continued as far as segment 12 as a narrow tube, the **oesophagus,** on which in segments 10 to 12 are three pairs of whitish sacs. These are glands secreting chalk possibly to neutralise the humic acid in the soil.

In segments 13 to 16 succeeding the oesophagus we find a rounded **crop**, and this is followed by the **gizzard**. The crop serves as a storehouse for the food, while the gizzard is a kind of mill in which it is ground up. The remainder of the digestive tract consists of a narrow tube, the **intestine**, continued right to the end of the body. The

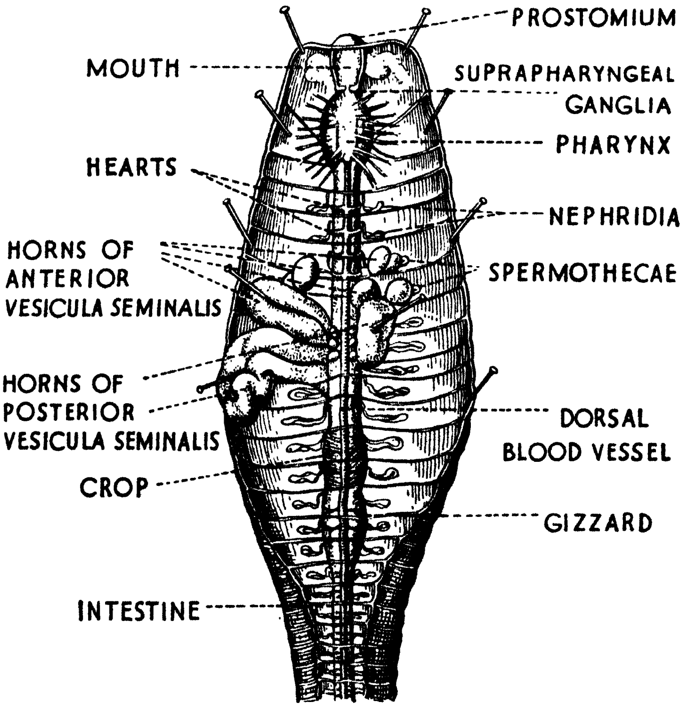


Fig. 44. Dissection of Earthworm.

inner wall of this tube consists of a layer of somewhat rectangular cells, which are glandular and secrete digestive juices. This layer corresponds to the endoderm of hydra, and because it covers a surface, it is called **epithelium** (Fig. 45). Immediately next to the epithelium occurs a

layer of muscular tissue, which consists of two parts, one part with the fibres running round the tube, circular muscle, and the other with them running lengthwise with the tube, longitudinal muscle (Fig. 46). The dorsal wall of the intestine is infolded, forming the **typhlosole.**

The outer surface of the intestine is covered with yellow cells called **chloragogenous tissue.** They contain yellow granules of nitrogenous waste products formed during digestion, and extracted by these cells from the blood.

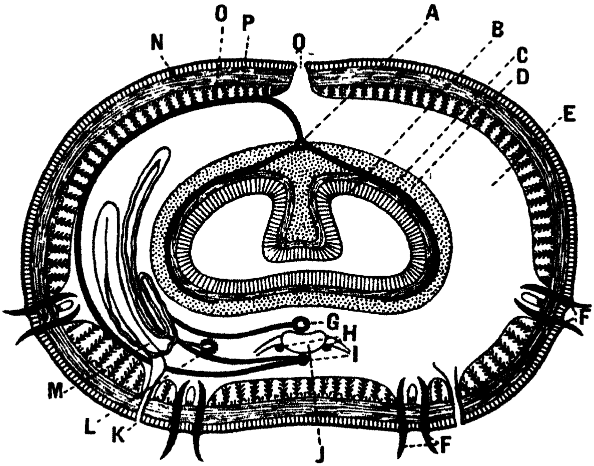


Fig. 45. TRANSVERSE SECTION OF HINDER REGION OF EARTHWORM. (After Howes, altered.)

A, Dorsal blood vessel; B, Epithelium; C, Muscle; D, Yellow cells; E, Coelom; F, Chaetae; G, Ventral blood vessels; H, Lateral-Neural blood vessels; I, Sub-Neural blood vessels; J, Nerve cord; K, Nephridiopore; L, Nephrostome; M, Nephridium; N, Epidermis; O, Longitudinal muscle; P, Circular muscle; Q, Dorsal pore.

The cells fall into the coelom, break up and thus the waste products pass into the organs of excretion called **nephridia** (Gk. *Nephro*—kidney), of which there are two in each segment except the first three and the last. A nephridium

is essentially a long tube bent several times along its length (Fig. 47). At one end of it is a funnel, the nephrostome, which is just in front of a septum. The narrow tube leading from this passes through the septum into the next body segment behind. The narrow tube is very winding and lined in places with cilia. Eventually it widens and this region is completely lined with cilia. Then

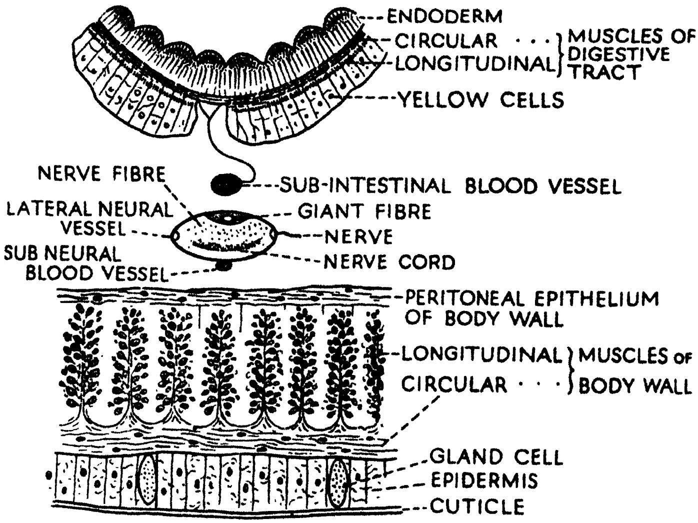


Fig. 46. EARTHWORM.
Part of Transverse Section of body (highly magnified).

follows a still wider non-ciliated region, and finally a very short, wide, muscular tube leads to the nephridiopore on the surface of the body. The loops of the nephridium are surrounded by tissue containing fine blood vessels. The cilia cause a stream of watery fluid from the body cavity to flow through the nephridium, and this carries with it waste products, including those from the yellow cells. The action of the muscular part of the tube causes the

fluid to be excreted through the nephridiopore. The structure of a nephrostome is shown in Fig. 47.

3. RESPIRATION AND CIRCULATORY SYSTEMS

As with all animals the worm must obtain a supply of oxygen to cause slow combustion of the food materials, and thus give it energy. The products of this combustion are carbon dioxide, water, and nitrogenous substances. It has already been shown how the nitrogenous substance and water are excreted from the body.

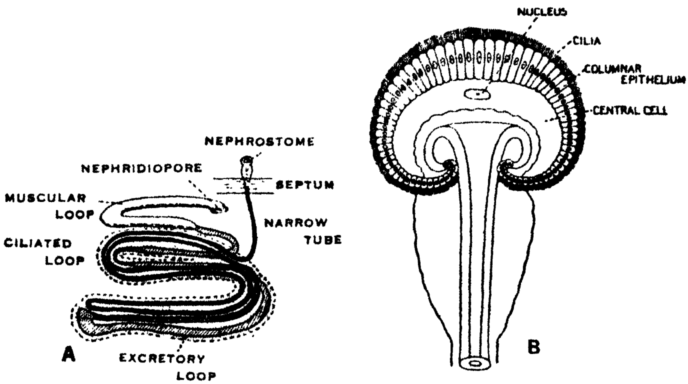


Fig. 47. EARTHWORM.
A, Nephridium; B, Nephrostome.

A worm has no nostrils through which oxygen may enter. It literally breathes all over its body, for, provided the skin is moist, oxygen diffuses through it. If a worm is allowed to dry it dies of suffocation, since it cannot in those circumstances obtain sufficient oxygen.

In an animal that possesses so complicated a body it is necessary that the oxygen should circulate to every part, since every part needs it. This is brought about by the fluid known as blood, which contains the red colouring-

matter with which oxygen readily combines. The red pigment is known as **haemoglobin,** and there are **colourless** cells in the fluid known as **corpuscles.** Blood is contained in tubes known as blood vessels which constitute the circulatory system.

There are three main blood vessels in the worm's body.

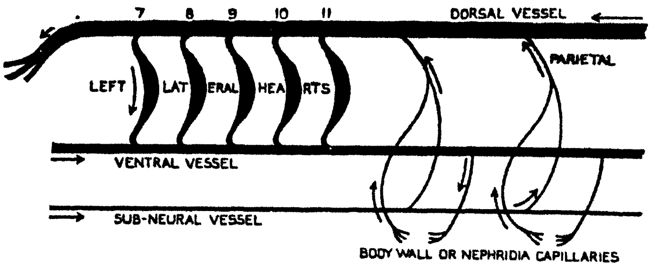


Fig. 48. EARTHWORM.
A Longitudinal Diagram of the Blood Vessels.

They extend the full length of it; one lies near the dorsal surface and is therefore called the **dorsal vessel;** the other two are nearer the ventral surface, and the larger of these is the **ventral vessel.** The third lies immediately below the nerve cord and hence is named the **subneural vessel** (Fig. 48). There is also a **lateral neural vessel** on each side of the nerve cord.

The dorsal and ventral vessels are connected near the head end by five vessels like hoops. These pulsate rhythmically, owing to muscles in the walls, and thus drive the blood round the body. They therefore answer the purpose of hearts. The dorsal blood vessel and the five "hearts" are visible in the dissection (Fig. 44). The walls of the dorsal vessel contract and the blood flows forward in it. Many small vessels branch off from it to the intestine, and two large vessels are given off in the tenth segment to the oesophagus, while in the front it

breaks up into branches for the pharynx. The blood from the dorsal vessel travels through the five "hearts" into the ventral vessel, where it flows backwards. The sub-neural vessel is also connected with the dorsal vessel by **parietal vessels,** two of which occur in every segment of the intestinal region (Fig. 49). The blood flows backwards in the subneural and lateral neurals. From the ventral vessel there are branches to the skin and nephridia, where they break up into exceedingly fine vessels called **capillaries.** By the time the blood has reached these capillaries its colour has darkened because it has been deprived of oxygen; it also contains nitrogenous waste materials and

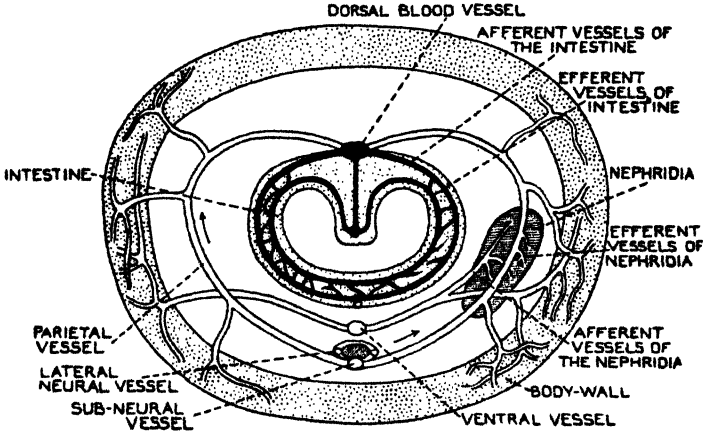


Fig. 49. Earthworm.
Transverse Section showing the Blood-Vascular System.

carbon dioxide. The nitrogenous materials pass through the thin walls of the capillaries into the nephridium tube, and thence are expelled from the body. The carbon dioxide diffuses through the thin cuticle covering the moist skin and is replaced by oxygen, which restores the red colour of the blood by forming oxyhaemoglobin.

4. NERVOUS SYSTEM

The worm also has need of a sort of telegraph system, whereby messages, with regard to its sensations, can be conveyed to muscles capable of executing movements to procure its safety or comfort. This system consists of a **nerve cord** running ventral to the alimentary canal. The cord gives off three pairs of branches, **nerves,** in every segment (Fig. 50), and these ramify so that all organs in that segment are in communication with the nerve cord. If some sensation due to these fine nerve branches arises in the worm's skin, it travels along a nerve to the nerve cord, whence a return message is communicated to the muscles in the skin, and these move the worm's body as needed. This is called a **reflex action** (Fig. 51).

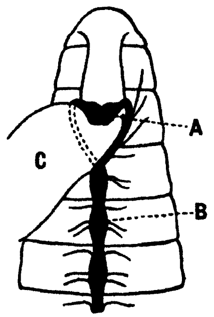


Fig. 50. EARTHWORM. Central Nervous System, Anterior end. (After Howes.)
A, Suprapharyngeal ganglia; B, Nerve cord; C, Pharynx.

The muscles in the body wall of the worm are visible in a transverse section (Fig. 45), and consist of circular and longitudinal muscle, as in the intestine. Outside the muscle is a layer of epithelial cells, the epidermis, some of which are glandular (Fig. 46), secreting a fluid to keep the skin moist. Over the epidermis is a cuticle, but this is perforated wherever a glandular cell occurs.

At the anterior end the nerve cord divides into two branches, each of which swells slightly at the end. The branches curve round the pharynx so that the swellings or **ganglia** lie side by side near the dorsal surface. The pair of ganglia seem to represent the beginning of a brain and are called suprapharyngeal ganglia. They are visible in the dissection (Fig. 44). The worm's nervous system makes it very sensitive to vibrations, and it seems

able to feel changes in light. It seems to possess some kind of taste, and possibly smell, since worms kept in a wormery (see Appendix) will select and drag into their burrows first strong-tasting and smelling leaves, such as onion.

5. REPRODUCTION

Any earthworm possesses both male and female gametes, and is therefore called **hermaphrodite.** There are two pairs of **testes,** one pair attached to the septum between segments 9 and 10 and the other to that between 10 and 11 (Fig. 52). The sperm mother cells pass out of the testes into large, branched white pouches, **seminal vesicles,** where they develop further. The seminal vesicles are very evident in the dissection (Fig. 44). The development of spermatozoa is shown in Fig. 53. The sperm mother cell divides into a number of portions, each containing a nucleus, and these portions appear as swellings on the surface of a round mass of protoplasm (Fig. 53). Since this whole structure looks

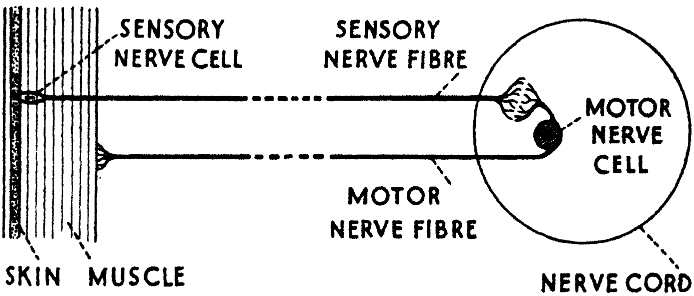


Fig. 51. EARTHWORM.
Diagram of Reflex Action. N.B.—Cells and fibres are on a larger scale; fibres should be much longer.

something like a mulberry it is called a **morula,** and during the course of its development reduction division occurs. Each nucleated portion elongates and becomes a **spermatozoon** with a large nucleus, very small head of

protoplasm, and long, slender cilium (Fig. 53, 4 and 5). The central mass of protoplasm to which they are attached gets used up during their development.

Communicating with the seminal vesicles are **seminal funnels** (Fig. 52), lined with cilia. Tubes from the pair on each side lead into a duct called the **vas deferens**, and this opens on the body surface in segment 15. The cilia cause the sperms to travel into the ducts, and they leave the body in order to fertilise the eggs of another worm. Some of the contents of a seminal vesicle may be mounted on a slide and examined. They may be stained (see Appendix) and made into a permanent microscope preparation. If a slide is prepared a tiny organism called monocystis, the structure and life history of which are given in Chapter VI., will probably be found, as well as stages in the development of sperms.

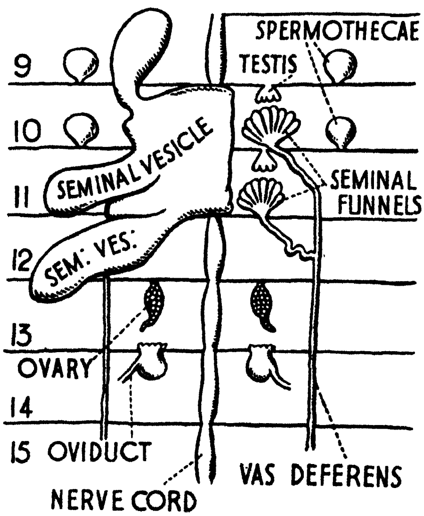


Fig. 52. Reproductive Organs of Earthworm.
Dissection from dorsal side. (After Marshall and Hurst, altered.)

The **ovaries** are attached to the septum between segments 12 and 13. They contain a number of cells, formed by reduction division, and these are the ova. When ripe they escape from the narrow end of the ovary (Fig. 52), into the body cavity. They then pass into two funnels occurring in the next septum back. From these lead two

oviducts which open, in segment 14, on the surface of the body. Attached to each oviduct is a little bag in which eggs may be stored.

In addition to the organs already described there are two spermothecae, ingrowths of the skin, between segments 9 and 10, and 10 and 11. They receive ripe sperms from another worm, for although the worm is hermaphrodite, its eggs are **cross-fertilised.** Worms pair at any time of the year in warm, damp weather. They place their ventral sides together with their heads pointing in opposite directions as shown in Fig. 54.

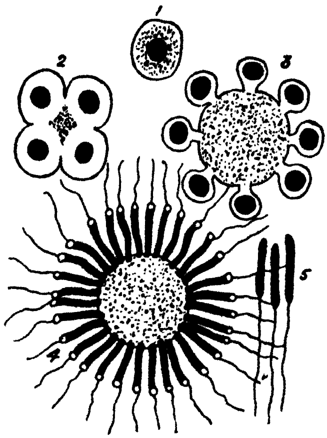


Fig. 53. DEVELOPMENT OF SPERMATOZOA OF LUMBRICUS.

The clitellum of one worm is attached to segments 9-15 of the other. This attachment is helped by a glandular secretion and also by the chaetae. From the epidermis mucus is secreted, making a slime-tube round each worm. From each worm spermatozoa are shed simultaneously from the openings of the vasa deferentia in segment 15. They travel inside the slime-tube along lateral grooves in the skin to the clitellum. Later they collect in the grooves between segments 9, 10, and 11 of the other worm and pass into the spermotheca.

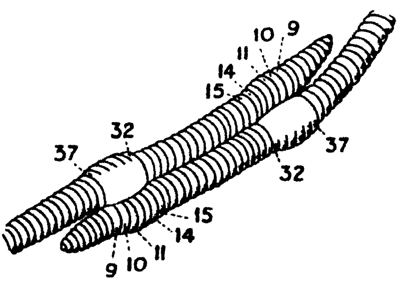


Fig. 54. COITION OF EARTHWORM. (After Grove.)

The clitellum secretes a cocoon in the form of a broad band round the body to receive the eggs, and this is worked forward over the body. On arriving at segment 14 it receives the eggs, and at segments 9 and 10 the sperms from the other worm. These sperms then fertilise the eggs, and the cocoon still passes forward, until finally it is free of the body. Its two ends then close up; and it is left in the earth as an oval, brownish object, about the size of a wheat grain. Usually only one of the contained ova develops into a young worm.

If an earthworm is cut across in two, the head end will grow a new tail and the tail end a new head, although the latter takes place rather slowly. This is possible because all the segments of a worm's body are so similar. The reproductive organs only occur in certain segments and there are no excretory organs in the first three and last segments; but otherwise each contains some part of all the organs in the body. This repetition of parts is called **metameric segmentation.**

CHAPTER VI

SOME PARASITES

1. INTRODUCTORY

The plants and animals so far considered have each been living their own independent lives. The plants have been green and therefore able to use the energy from the sunlight in connection with building up their food. They have only needed a supply of carbon-dioxide, water, and mineral salts to feed upon. The animals in their turn have been able to obtain and consume animal and plant material. There are other plants and animals which live either on, or inside, another plant or animal, in such a way that they take food from the other living organism. It was mentioned in the last chapter that Monocystis might be found in the earthworm. A plant or animal living at the expense of another living thing's energy is called a **parasite**. Such a creature has devised a method of stealing food from the creature it has made its **host.** Plants which have acquired this habit do not possess chlorophyll, and therefore are unable to feed themselves as normal green plants do, but must have carbohydrates and proteins ready made. Animals have become specialised to obtain food from other living animals and to live in conjunction with them.

Parasites are usually disease-producing organisms. It must not be supposed that the host plant or animal raises no objection. A fierce struggle ensues when any creature is attacked by a parasite, and the latter does not always win in the fight, either entirely or even for a time.

2. MONOCYSTIS

This animal can be examined in the slide prepared from the seminal vesicle of earthworm (see Appendix). Amongst the sperm mother-cells will be found some larger and elongated. Each of these is a cylindrical, unicellular and uninucleate animal, which has endoplasm surrounded by ectoplasm, and the whole is bounded by a cuticle (Fig. 55, C). It can move about by contractile threads of the ectoplasm squeezing the endoplasm from one part of the body to another.

When Monocystis is about to reproduce, two individuals come into contact, and these will function as gametocytes, that is, cells which will form gametes. The two gametocytes become surrounded by a firm wall to make a cyst (Fig. 55, D). The nucleus of each gametocyte then divides into a number of small ones. They pass to the surface of the protoplasm, which divides into portions around each nucleus. There is some protoplasm left in the centre (Fig. 55, F). Each nucleus, with its portion of protoplasm, forms a gamete, and they conjugate in pairs. In one species it is said that the gametes formed by one gametocyte are round, and those formed by the other one more pear-shaped. Two dissimilar gametes conjugate so that **cross-fertilisation** occurs. The result of the conjugation is a **zygote** (Fig. 55, G), which produces boat-shaped spores (**pseudonavicellae**) (Fig. 55, H). The nucleus of the spore then divides into eight. Each nucleus is surrounded by a portion of protoplasm, and some remains unused. There are then eight long, narrow structures inside the spore wall, and these are called **sporozoites** (Fig. 55, L, M). The cases containing these sporozoites are called sporocysts, and are probably only liberated on the death of the worm. They have been found in the intestines of worm-eating animals such as birds and frogs, where the sporocyst becomes

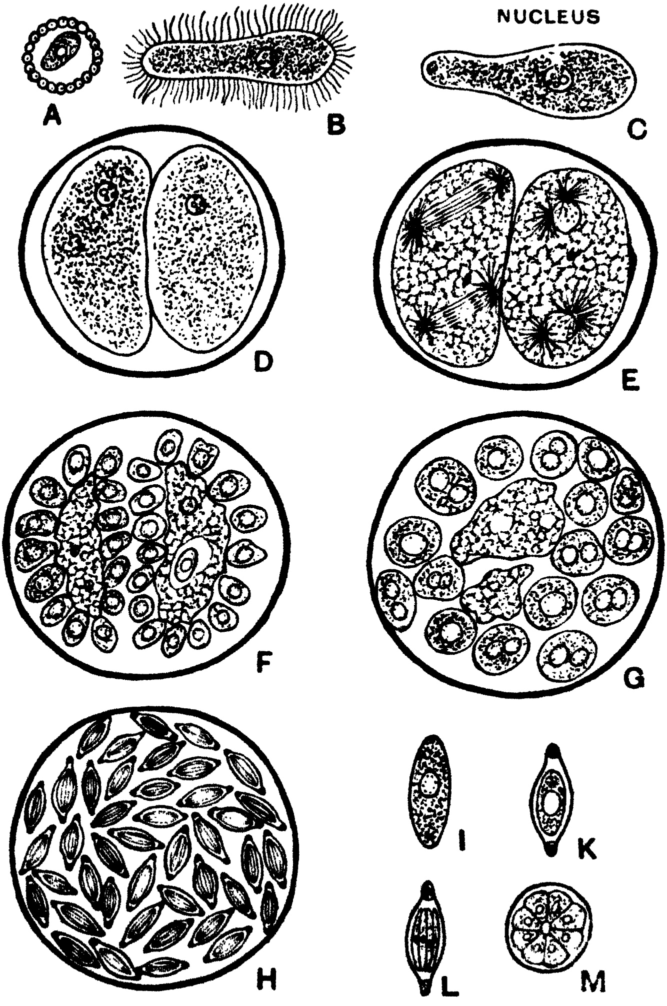
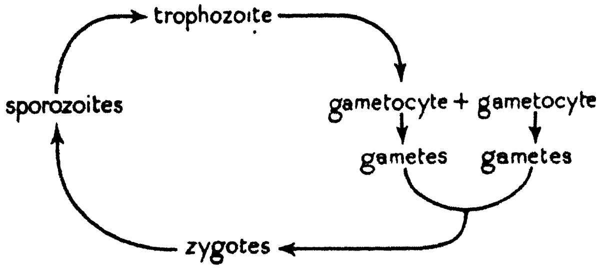


Fig. 55. Life-History of Monocystis Agilis.

A, Young trophozoite in residual protoplasm of a sperm-mother cell; B, Adult trophozoite surrounded by spermatozoa of earthworm; C, Free trophozoite; D, Gametocyst containing two gametocytes; E, Gametocytes showing nuclear division; F, Gametes formed from gametocytes, and residual protoplasm; G, Zygotes, some with two separate nuclei, some with two fused into one; H, fully developed spores (pseudo-navicellae) in gametocyst; I, young stage of spore with single nucleus; K, spore with sporocyst formed but nucleus undivided; L, fully developed spore containing eight sporozoites; M, transverse section of mature spore.

dissolved. In this way the sporozoites eventually reach the soil to be eaten by an earthworm.

Having arrived in the seminal vesicle of a worm once more, a sporozoite enters a sperm mother cell, remaining in it while it forms spermatozoa, and feeding on its protoplasm. In this feeding stage of its existence it is called a **trophozoite** (Fig. 55, A). It gradually assumes the shape of an adult monocystis, and this is at first surrounded by the cilia of the worm's withered sperms (Fig. 55, B). The following is a graphical representation of the life cycle:—



3. PYTHIUM

If seedlings are freely watered and kept in an enclosed space so that the atmosphere is damp, they will all bend over and die off. Gardeners term this "damping off." This is due to the attack of a plant belonging to the class known as fungi. A **fungus** has no green colour and therefore must have other organic matter, either living or dead, on which to feed. By growing some cress seeds under a bell-jar and keeping them well watered, a parasitic fungus called Pythium may be induced to grow on them.

Pythium is a filamentous structure, but there are no transverse cell walls. It is one very long, narrow cell, which contains a cytoplasmic layer in which are many small nuclei and vacuoles containing cell sap. There are no chloroplasts, the filament is colourless. This structure

grows and branches, making its way in and between the cells of the host plant in which it is growing. The filaments are called **hyphae,** and the whole plant body, that is, the entire mass of hyphae, is called a **mycelium.** Some of the hyphal ends will undoubtedly wander to the little openings, known as stomata, which are found on the surface of the leaves. When this happens, the end of the hypha emerges through the stoma into the atmosphere; here it swells and a transverse wall separates this more or less spherical end from the rest of the hypha (Fig. 56). It is known as a **gonidangium,** and after a while it is detached. If the surface of the leaf is moist the gonidangium almost immediately puts out a little tube, the end of which expands into a thin-walled spherical vesicle into which the protoplasm and nuclei pass and divide. The wall of this structure bursts, and each nucleus, surrounded by protoplasm, escapes as a small spore with two cilia, known as a zoospore or **zoogonidium.**

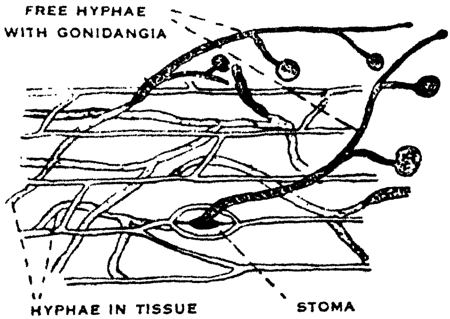


Fig. 56. PYTHIUM.
Epidermis of a plant attacked by the fungus.

The term zoogonidium is used because it occurs on the gametophyte and not on the sporophyte, and similarly we have a gonidangium instead of a sporangium. The zoogonidia are dispersed and swim about in the moist surroundings. They finally settle down either on the same seedling or another, draw in their cilia, and germinate; that is, they send out a small hypha which very soon enters the seedling, either by means of a stoma or, should

one not be near, the tip of the hypha secretes a substance which dissolves away sufficient of the cell wall of an epidermal cell of the host plant to obtain an entrance. This is known as asexual reproduction, and is a very rapid method of increase during favourable conditions. If conditions are not quite so favourable, the gonidangium produces a new mycelium immediately, instead of forming zoogonidia.

When the host plant is beginning to " damp off " and available food for the fungus is consequently getting scarce, swellings occur in the mycelium which is in the host tissue. These may be terminal or may occur at other parts of the hyphae. They become cut off by transverse walls, so that they are approximately spherical and are called oogonia (Fig. 57). Each **oogonium** wall contains a central nucleus surrounded by protoplasm, forming the oosphere, which is the female gamete. Surrounding the oosphere is a mass of protoplasm known as the periplasm, in which are embedded a large number of small nuclei.

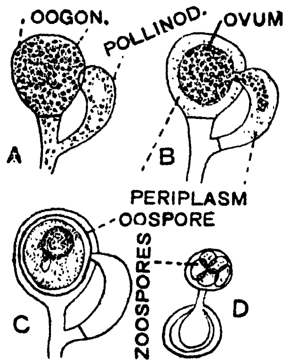


Fig. 57. Sexual Reproduction in Pythium.
B, Fertilisation; D, Germination of oospore.

Arising very close to the oogonium, a thin branch develops, called the **pollinodium.** Here also is a periplasm marked off from the central uninucleate part which is the male gamete. The wall of the pollinodium grows out towards that of the oogonium, and a little tube is formed connecting them. Along this tube the male gamete passes and enters the oosphere cytoplasm. The two nuclei, that is, the nucleus of the male gamete and that of the female gamete, then unite, completely fusing, so that a uninucleate zygote known as an **oospore** is formed.

Around this a very thick wall develops, which is greatly added to by the periplasm. The ripe oospore contains a large amount of oil. The oospore is liberated from the oogonium and eventually from the host cell by decay of the latter, and then rests for a while.

When conditions are again favourable for germination, one of three things happens: either a new mycelium is produced which enters another plant; or a number of **zoospores** emerge from the oospore; or the contents of the oospore pass into a thin vesicle and there divide to form several zoospores. When zoospores are produced, they form a new mycelium which infects a new host, and in these cases several new plants are obtained from one oospore instead of only one as when the oospore produces a mycelium directly.

4. CYSTOPUS AND PERONOSPORA

Closely related to Pythium are many other fungi which are parasitic on other plants than cress. Cystopus, also known as Albugo, is very commonly found on the leaves and stems of Shepherd's Purse and members of the Cabbage group generally, as white patches. Peronospora occurs as a mildew on spinach, onions, and cabbages.

The hyphae send into the epidermal cells little absorbing organs known as **haustoria,** which are swollen at the end in Cystopus and branched in Peronospora (Fig. 58).

The life histories of these two parasitic fungi agree very closely with that of Pythium. During the growing period of the host plant gonidangia are formed on hyphae called gonidiophores. In Cystopus they occur in rows on short, unbranched hyphal ends (Fig. 58) in clusters which eventually break through the epidermis or skin; while in Peronospora they occur on much-branched ends of hyphae, which push through the stomata (Fig. 58). In both cases oospores are produced later in the season as conditions become unfavourable.

5. RUST FUNGI

These are so called because they have the appearance of spots of rust on the plants they have attacked. The most well known is the **Rust of Wheat,** *Puccinia graminis.* Young wheat plants are attacked by spores which penetrate into the tissues of the green stem and leaves. The plant struggles on, but reserve food does not collect, so the grain is quite useless for food.

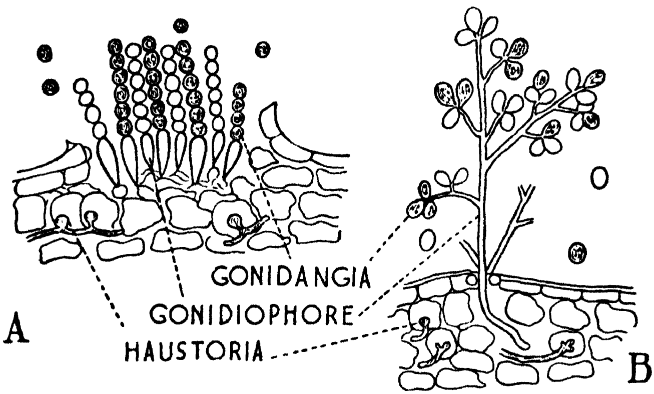


Fig. 58. A, Cystopus. B, Peronospora.

The hyphae of this fungus are multicellular and penetrate into the tissues of the host plant. During the summer crops of spores known as **uredospores** are made, and burst through the epidermis of the host (Fig. 59). Uredospores are produced on very slender stalks; each has two nuclei and is surrounded by a thin cell wall and an outer, thicker, protective one. These spores when fully developed are blown off by the wind or carried away by insects. Many of them alight on the leaves and stems of wheat plants, where they begin to grow at once. From each spore hyphae are put out, and run along the surface of a wheat

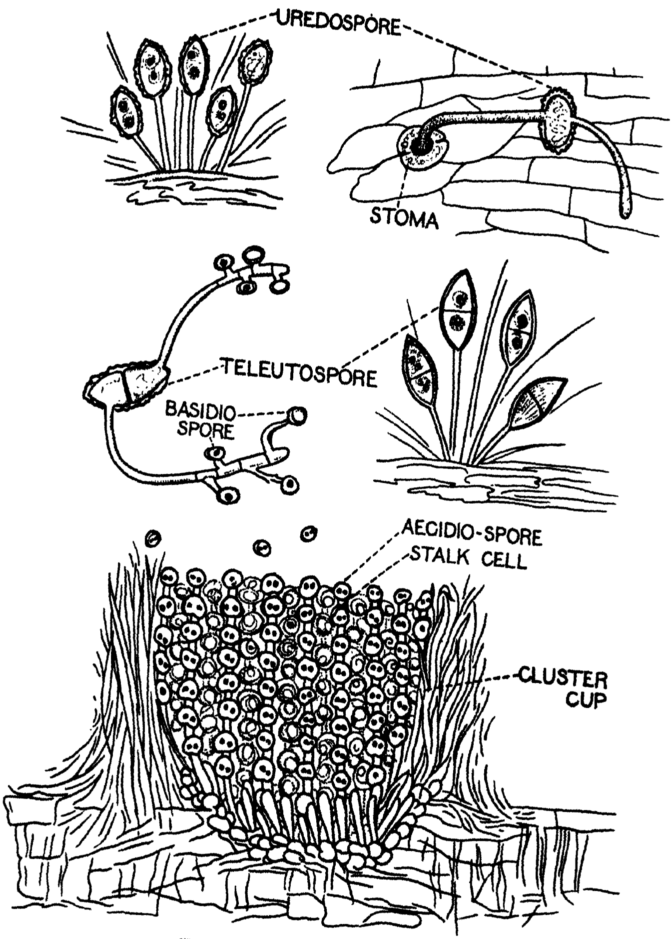


Fig. 59. Rust of Wheat.

plant until one of them finds a stoma, which is a pore in the epidermis, and through which it will enter. This one then develops in the host tissues, while the less fortunate die away. Many crops of uredospores may develop during the season, but as the summer goes on and the wheat plants reach maturity, a new type of spore appears, forming a black rust.

This type also occurs in groups which at first begin to appear amongst the uredospores. Like the uredospores, they also are borne on stalks, but each has four binucleate cells, and is dark brown in colour (Fig. 59). They are called **teleutospores,** and have much stronger, resistant coats, and rest during the winter. While the teleutospores are developing the two nuclei fuse, so that when they are shed they are uninucleate. The germinating teleutospores take their nutriment from decaying matter, and so the fungus is temporarily a saprophyte. From each cell of the spore a small tube is put out, which becomes divided into four cells, from each of which a small spherical spore is budded off (Fig. 59). These are known as **basidiospores,** and they too are uninucleate.

Wheat crops suffered considerably from this disease, and it was a long time before it was discovered what happened to the basidiospores, or how the new crop became infected again. At last it was found that basidiospores are conveyed by wind or insects to Barberry (*Berberis*) bushes. Here they develop and produce patches on the foliage in which occur a number of cup-shaped areas, which are full of spores, called **aecidiospores** (Fig. 59). The mycelium formed from the basidiospore ramifies in the tissues of the barberry leaf, until fusion occurs between two of its cells. The nuclei remain separate from one another, though associated together in a mass of protoplasm obtained from two cells. This is the stimulus for the production of a "cluster cup," or group of aecidiospores. The compact mass of hyphae having developed at the base of the cup,

the ends of basal ones project into it as little stalks and, from their tip, cells are repeatedly cut off and form a little stalk cell and an aecidiospore. These are all binucleate, each cell having continued to possess two nuclei, which have not so far fused together. On the Barberry there are also some miniature cups which contain very thin hairs and very small round bodies. These are called **pycnidia.** No function has been found for them at the present time. They may be degenerate male organs.

The aecidiospores become scattered gradually, layer after layer, as they reach the surface of the cup and the wind plays on those which have become loose by the drying up of the stalk cell. These become ripe just as the wheat seedlings are growing and cause the rust of wheat. The life cycle of the fungus, known as *Puccinia graminis* on the Wheat, and *Aecidium berberis* on the Barberry, is thus completed. This fungus has three stages in its life history, one parasitic on wheat, another parasitic on Barberry, and a third saprophytic on decaying matter in the soil.

It is interesting to notice that the two nuclei which came together in the early development of the aecidiospore cup remain separate all through the life of the fungus on the wheat until it is preparing for the winter rest, but in the teleutospore they fuse and become one. Now that the life story of this fungus is known, it is quite easy to prevent the disease. If there are no barberry bushes for the basidiospores to develop upon, there can be no aecidiospores to infect the wheat plants. When there are several distinct hosts needed a fungus is said to be **heteroecious.**

There are many other fungi in this group with similar life histories, many of which are still incompletely known, and consequently are very difficult to eradicate; whereas with further knowledge they could probably be stamped out with comparative ease. Many of our fruit trees have diseases which are thought probably to have in their life history other stages on plants which are regarded as weeds.

6. THE MALARIAL PARASITE

The slightly different forms of Malaria or ague are caused by three different organisms which are closely related, and have the generic name, *Plasmodium*. Plasmodium is a unicellular animal, and its adult form is called a **trophozoite,** as in Monocystis. It lives in those rounded, red protoplasmic bodies floating in blood known as red corpuscles, and is itself at first round, with a very large vacuole in the centre and, of course, a nucleus. It absorbs food all over its surface and as it grows (Fig. 60, i-iv), it puts out pseudopodia and acquires granules of red colour, no doubt derived from the red blood corpuscle on which it feeds, hence it has also been called **Haemamoeba.**

When it is ready to reproduce it becomes round again (Fig. 60, v), and is then called a **meront.** The nucleus divides into about sixteen, each nucleus becomes surrounded by a piece of protoplasm, and the tiny separate bodies called **merozoites** collect round the remaining or residual protoplasm which contains the red granules (Fig. 60, 6-9). The corpuscle then breaks up, and it is this destruction of red corpuscles that is so dangerous to the host. Thus the meronts are set free in the blood. Each merozoite bores its way into a new corpuscle and becomes a new trophozoite. This reproduction is *asexual,* since the reproductive bodies are formed without conjugation. It continues until either the host begins to overcome the parasite or is about to die.

In the case of *Plasmodium falciparum,* which causes pernicious malaria, the trophozoites then become rounded, or crescent-shaped, and form **gametocytes** (Fig. 60, vi). These can develop no further unless the host is bitten by a mosquito, and they are therefore sucked into its body. Some gametocytes are male, others female. In the former, the nucleus divides and the daughter nuclei become thread-like, each being surrounded by a thin layer of protoplasm,

CHAPTER VII

THE COCKROACH AND OTHER INSECTS

1. THE COCKROACH

There are two species of cockroach common in England. *Periplaneta orientalis*, the common cockroach (originally introduced from the East), is nearly black, and called the black beetle. Another species, *P. americana*, which has been brought here on ships and is spreading rapidly in our own country, is distinctly brown in colour, and larger than *rientalis*. The first species inhabits houses and the d is finding its way inland into houses from ships and .. Cockroaches hide away during the day, but are active at night, seeking and devouring any available food whether animal or vegetable.

2. EXTERNAL APPEARANCE

The insect consists of a **head** and segmented **thorax** and **abdomen.** The head bears two long, thin, pointed **antennae,** the thorax **three pairs of legs** and, except in the female of *P. orientalis*, **two pairs of wings.** These characters suggest that cockroach is an **insect** (Fig. 67). The fore pair of wings are dark in colour and horny, and when the cockroach is not flying they cover the hind pair of wings, which are thin and transparent.

In a dorsal view of the insect, as in Fig. 67, the **head** can scarcely be seen, because it is tucked underneath, but from a side or front view the head is of fair size and prominent (Fig. 68).

The segments of the head are masked, but the appendages give a clue to the presence of some of them. The animal's

it. If a live insect be kept in a glass vessel and given food, such as pieces of bread, the way in which it uses the mouth parts can be studied. The way in which the long, sensitive antennae are used for feeling can also be noticed.

The neck, joining head to thorax, is unprotected by hard cuticle, and is therefore soft. The **thorax** consists of three distinct segments, prothorax, mesothorax, and metathorax (Fig. 67). Each segment bears a pair of legs, but only two pairs are shown in the figure. Each segment has a dorsal plate, the tergum, and a ventral one, the sternum.

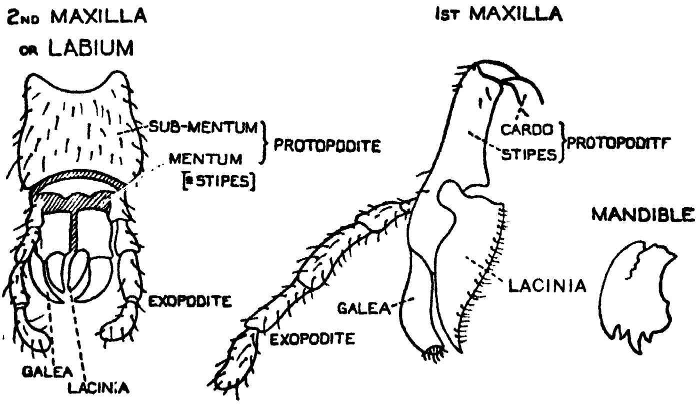


Fig. 69. COCKROACH.
The Head Appendages. (Leigh-Sharpe.)

Fig. 70 shows the parts of the **leg.** The bristles are used in cleaning the body and the two hooked claws at the end of the leg are for climbing. Between the claws is a pad (pulvillus) to assist in walking. The mesothorax bears a pair of dark, horny **wings,** which act as covers for the more delicate pair of wings arising from the metathorax, and are called tegmina (Fig. 67). The hind wings are transparent, and are folded lengthwise and laid along the back, when not in use. The cockroach's wings are simply outgrowths of the cuticle strengthened by ridges called nervures. In

the female of the common cockroach they are practically absent, the fore wings being represented by very small, useless outgrowths.

The **abdomen** consists of ten segments, each with a tergum and sternum. The eighth and ninth segments telescope into one another and into the tenth, and are not therefore visible. The only appendages of the abdomen occur on the tenth segment. They are segmented and sensory, and known as **anal cerci.** The posterior opening of the alimentary canal, the **anus,** occurs beneath the tergum of the tenth segment, and a pair of **podical plates** either side of it possibly repre- the tergum of an eleventh segment. The opening for the escape of the gametes, called the **genital aperture,** is below the anus. In the male, a pair of slender, unsegmented styles arise from the ninth sternum and project backwards like the cerci. In the female there is a genital pouch formed by the seventh sternum.

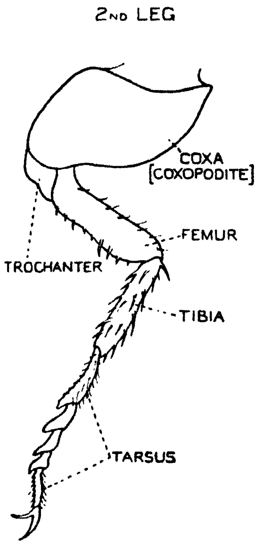


Fig. 70. Leg of Cockroach.

3. RESPIRATORY ORGANS

These consist of much-branched tubes, called **tracheae,** strengthened by a horny substance, known as chitin, which is laid down spirally (Fig. 71). Chitin also occurs in the cuticle. The tracheae communicate with the atmosphere by means of ten pairs of openings, called **spiracles,** two of which occur at the sides of the thorax, and the remaining eight between the terga and sterna of the first eight

abdominal segments. Beneath the cuticle, there are paired triangular muscles attached to the terga (Fig. 72). Those marked alary muscles move the wings; those of the

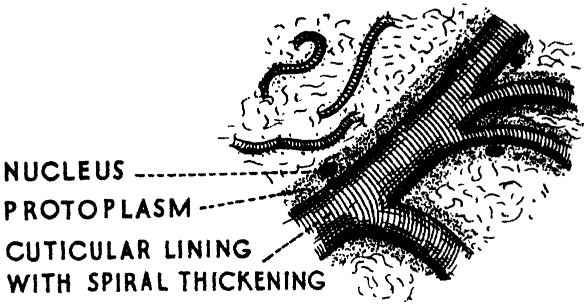


Fig. 71. COCKROACH.
Part of Tracheal tissue.

abdomen cause it to contract and expand so that air is continually entering and being expelled from the spiracles. The branches of the tracheae penetrate into all parts of the body carrying oxygen. The expansion and contraction of the abdomen can be noticed in the living cockroach.

4. THE HEART

The heart is a straight tube, running the length of the body in the middle of the dorsal surface (Fig. 72). It is divided into thirteen parts, one for each body segment, each having a pair of openings called ostia. Surrounding it is a cavity or **sinus**, the pericardial space, leading into which are openings from the perivisceral cavity which surrounds the alimentary canal. The blood from all the organs of the body collects in this latter cavity, and the paired triangular muscles, as already mentioned, cause expansion and contraction of the abdomen and therefore of the perivisceral cavity. The blood flows from the perivisceral cavity into the pericardial cavity and thence into

the heart. Since the two cavities, or sinuses, collect blood and return it *to* the heart, they seem to represent veins. The blood leaves the heart by a vessel called the **aorta,** which may be termed an artery, since it conveys blood *from* the heart. There are no capillaries in the cockroach. On leaving the artery the blood simply bathes the organs to which oxygen has been conveyed by the tracheae. Such a **blood system** is described as **open,** whereas that of an earthworm is closed. The blood is colourless as it possesses no haemoglobin.

The cockroach has no coelom like that of the earthworm; since the body cavities are filled with blood they constitute a haemocoele.

5. DISSECTION

Cockroaches may be easily killed by putting them into a bottle containing cotton wool soaked in chloroform. The external features should be noted carefully. Head appendages must be removed to find the parts. They may be mounted in glycerin and examined with the microscope. If the ventral surface of the animal be examined, with the abdomen slightly stretched, the spiracles are noticed between the segments.

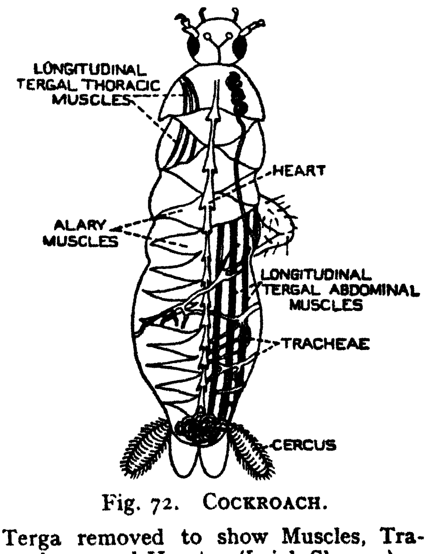


Fig. 72. COCKROACH.
Terga removed to show Muscles, Tracheae, and Heart. (Leigh-Sharpe.)

To dissect the cockroach, it must be fixed to a sheet of cork, by means of small pins, with the dorsal surface

upwards. Another method of fixing it is to hold it with the under-surface in melted paraffin wax, until this cools and solidifies. The wings must be cut off and also each tergum. The heart lies very close below the terga. A large "fat body" hides most of the organs. The tracheae will be noticed, and the alimentary canal must be freed from the fat body (which can be removed), and unravelled. A portion of the fat body examined under the microscope shows the tracheae.

6. THE ALIMENTARY CANAL

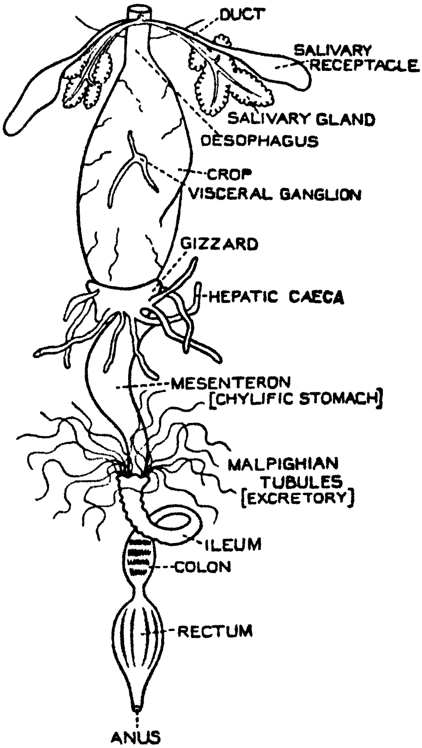
This may be divided into fore-gut, mid-gut, and hind-gut. Only the mid-gut, or mesenteron, corresponds to the alimentary canal of the rabbit, frog, and dogfish. The fore- and hind-guts are lined with a continuation of the external skin or cuticle, so they are just ingrowths from the anterior and posterior ends of the animal.

The fore-gut consists of the mouth containing a tongue-like outgrowth, and leading into this is a pair of ducts from the salivary glands (Fig. 73). The saliva, secreted by the glands, passes along the ducts into the mouth, and it has in it a substance which converts the insoluble starch in the cockroach's food into a soluble sugar, glucose. All food materials must be rendered soluble before they can pass out of the alimentary canal into an animal's body. There are a number of different substances which change the various classes of food-stuffs in the diet into soluble form, but they are all alike in that, being themselves present in very small quantity, they bring about a change in large quantities of some other substance without being altered in any way themselves. All are called **enzymes**, and the enzyme in saliva converts starch into glucose.

The mouth leads into a tiny oesophagus in the neck, and this into a comparatively large crop, which continues into a gizzard. Although these parts have received names corresponding to those given in a bird and other animals,

they do not exactly correspond to them, as they are formed quite differently. The gizzard contains six tooth-like projections of the cuticle arranged in a circle (Fig. 73), and behind them are swellings covered with bristles, which act as strainers. The hepatic caecae, leading into the gizzard, secrete a digestive fluid containing enzymes. The gizzard projects, like a funnel, into the mid-gut.

The hind-gut is somewhat coiled and divided into ileum,



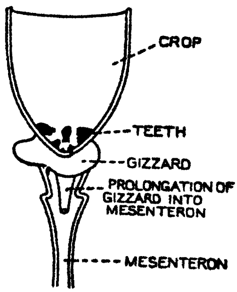


Fig. 73. Cockroach.
Alimentary Canal. (Leigh-Sharpe.)

colon, and rectum, but again these parts do not correspond exactly to those so named in other animals. The malpighian tubules at the beginning of the hind-gut are excretory organs, their function corresponding to that

of kidneys. They excrete from the body water and nitrogenous waste in the form of uric acid. The fat body also appears to play some part in connection with the formation of uric acid.

7. NERVOUS SYSTEM

If the alimentary canal be removed, further organs are revealed. There is a double **nerve cord** with a swelling, or **ganglion**, in each of the first nine body segments (Fig. 74).

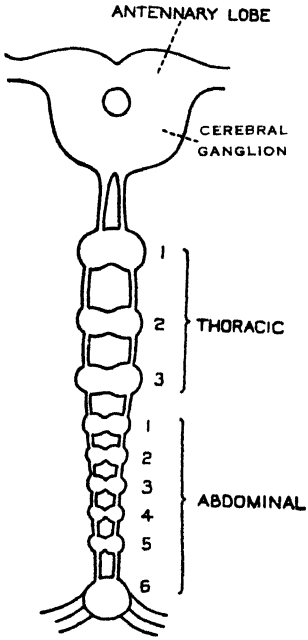


Fig. 74. Cockroach. Nervous System.

In addition to these ganglia there is a pair of **cerebral ganglia** in the head, dorsal to the oesophagus, and these constitute a kind of brain. From this a pair of nerves, **optic nerves**, run to the eyes, and another pair, **antennary nerves**, to the antennae (Fig. 75). There is also a ganglion below the oesophagus, **sub-oesophageal ganglion**, which is connected with the cerebral ganglia by the pair of **post-oesophageal ganglia**. Nerves from the cerebral and the post-oesophageal ganglia supply the alimentary canal.

The "brain" may be examined by fixing the head, with the anterior surface upwards, by means of a pin through the upper part of the epicranium, and another between the mandibles, and then removing the clypeus and the anterior portion of the

epicranium. The head can then be fixed, with the right side uppermost, and the gena and mandible removed.

The sense organs of the cockroach include the eyes for sight, the antennae, which have sense of touch and smell,

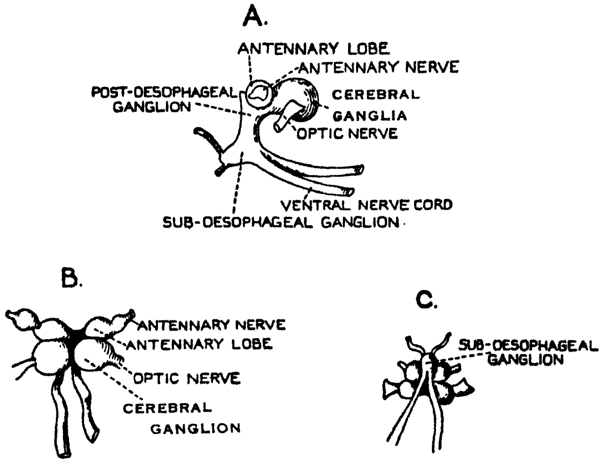


Fig. 75. Brain of Cockroach.
A, Lateral; B, Dorsal; C, Ventral aspects. (Leigh-Sharpe.)

and the maxillae, which may have some sense of taste. The anal cerci also possess sense of touch, as do some bristles on the body and possibly the fenestrae, two oval patches at the base of the antennae.

8. REPRODUCTION

The males possess a pair of testes to be found in segments four to six of the abdomen. In these will be found sperms consisting of a little protoplasm, a large nucleus, and a cilium. When ripe they travel along the tube, known as the vas deferens (Fig. 76), into a group of club-shaped processes—the vesiculae seminales—where they are stored until needed. They are destined to enter the body of a

female. The ductus ejaculatorius, along which they must eventually pass, opens between the ninth and tenth abdominal segments, and from here, therefore, the sperms escape. The opening is surrounded by thorn-like pieces—gonapophyses—and these interlock with similar structures in the female. The function of the conglobate gland is unknown.

The female body contains two sets of eight ovaries, one on each side of the body in the abdominal region (Fig. 77).

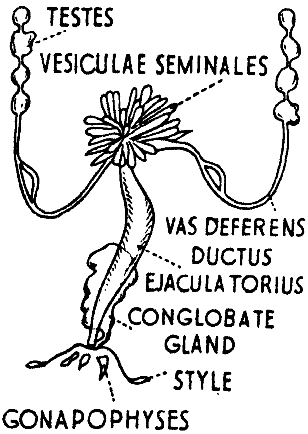


Fig. 76. Cockroach.
Male Reproductive System.
(Leigh-Sharpe.)

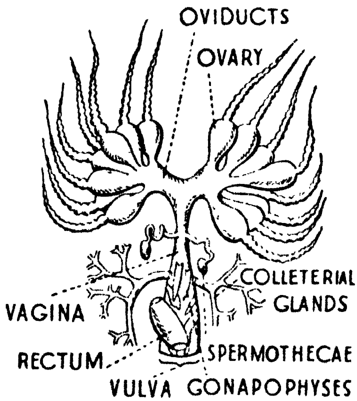


Fig. 77. Cockroach.
Female Reproductive System.
(Leigh-Sharpe.)

These ovaries unite into a short, wide oviduct, and the two oviducts unite into a vagina, which opens on the eighth abdominal segment, the opening being called the vulva.

In addition to ovaries, the female has a pair of bags—the spermothecae—in which the sperms from the male are stored.

The spermothecae open between the eighth and ninth abdominal segments, and are connected with the vagina by somewhat coiled tubes. The colleterial glands secrete

horny material, and open on the ninth abdominal segment. Sixteen eggs, one from each ovary, together with some sperms, are laid in a horny egg case.

The young insects resemble the adults exactly, except that they have no wings and are paler in colour. The firm, external body-covering is incapable of expansion, therefore as the insect grows it must be shed. After several moults the wings appear.

The number of different kinds of insects is enormous. It probably equals that of all the other animals together. The chief variation in the structure is in the mouth parts, because different insects indulge in different diets. The wings also vary. In many cases the life-history offers us an interesting study, because the creature hatched from the egg is utterly different in appearance from the adults, but, unlike an embryo, it is quite capable of fending for itself. It is called a **larva,** and at a certain stage in its life-history it changes into the adult form. This change is called its **metamorphosis** (Gk. *meta* = after: *morphe* = form). The adult form of an insect is called the **imago.** There are two principal types of life-history amongst the insects: (1) the young differ only very slightly from the adults, and gradually come to resemble them exactly by a series of moults, *e.g.* cockroach; (2) the larva undergoes considerable change and passes through a motionless stage when it is called a **pupa,** *e.g.* moth, butterfly, beetle, bee, wasp, ant. Although it is called a black beetle, the cockroach is not really a beetle. It resembles the beetles in that the fore wings are not transparent like the hind wings. Beetles, like the cockroach, have mouth parts adapted for biting.

9. OTHER INSECTS

A. The House-Fly (*Musca domestica*). A house-fly imprisoned in a closed test-tube can be examined closely. Clearly, it is an insect since it possesses three divisions of

the body, a pair of antennae, and six legs. It has only one pair of wings, but in place of the hind pair there are a pair of small drum-stick shaped things known as balancers, for it is possible that they assist in balancing the body (Fig. 78). Because it possesses only two wings, it is placed in the order Diptera. It has a pair of very large compound eyes (each consisting of about 400 facets), and also three simple eyes between them, but on the top of the head. In the female the space between the compound eyes is wider than in the male.

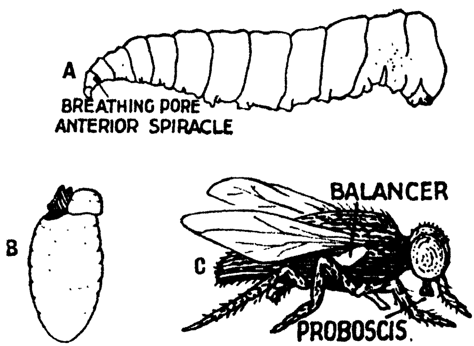


Fig. 78. Life-History of a House-Fly. A, Larva; B, Pupa; C, Imago.

On a fly's foot are two small cushions. These are slightly adhesive, and also create a vacuum between the fly's foot and the surface upon which it walks, so that the atmospheric pressure holds the foot firmly to the surface. It is owing to this that a fly can walk upon the ceiling.

If a few crystals of sugar are put into the tube and the fly watched when feeding on them, it will be seen to shoot out a tube which widens at the end. The wide end consists of two lobes, and channels in these lead into the mouth; the latter opens into a muscular pump, which draws up the liquid food. The oval lobes also have sense organs, probably of taste and smell. In the head are many air sacs and a good deal of blood not contained in blood vessels. When the air sacs expand, this blood is forced into the proboscis, causing it to be stretched out, just as

the finger of a glove can be blown out. When the proboscis is not in use the lobes close upon each other, and it is bent up, just as the arm at the elbow can be bent. The house-fly has no mandibles or maxillae. It cannot bite, or even pierce, its food. The proboscis is adapted entirely for sucking.

The female lays a tremendous number of groups of eggs in the dark crevices of substances which will form suitable food for the larvae, namely any decaying vegetable or animal matter. The eggs are about 1 mm. long, pearly white, and cylindrical. In warm weather they hatch in from eight to twenty-four hours. The larva is a creamy white, legless maggot about 12 mm. long. It is narrow anteriorly and widens towards the posterior end (Fig. 78). The body has twelve segments, as shown in the figure. It is apparently headless, as the head is withdrawn into the body. Segments six to twelve are provided with pads, and these, together with a hook-shaped process from the proboscis, enable the creature to move. The larva moults only twice.

While in the larval stage it must have moisture, but when fully grown it seeks a dry place; then the body contracts somewhat and becomes cylindrical. The skin is not shed, but it hardens, changes to a dark brown, and becomes the pupal case (Fig. 78). If it is warm the fly emerges in from three to four days. When only about eighteen days old, the female flies commence to lay eggs. It is thus readily intelligible why there are such vast numbers of house-flies. It is a dangerous insect, upon which man must constantly wage war, since it carries on its feet germs of many diseases, which it deposits on our food.

The bluebottle, or blowfly, is similar in detail, both in structure and in life-history, to the house-fly. It is known by its buzz, large size, and hairy, dark blue body. It enters the house to find meat upon which to lay its eggs, and if it

succeeds the meat will soon be teeming with maggots, for the eggs hatch as rapidly as those of the house-fly.

B. THE GNAT (*Culex pipiens*). There are many insects which pass the larval stage in water, although the imago may spend its life on land. On the surface of any fairly shallow water, on a spring or summer day, may be seen small, maggot-like creatures hanging head downwards from the surface of the water (Fig. 79). If the surface of the water be disturbed they sink out of sight. These are the larvae of gnats.

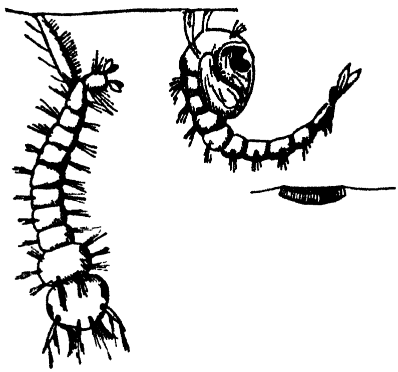


Fig. 79. LARVA, PUPA, AND EGG RAFT OF COMMON GNAT (*Culex pipiens*). The eggs are drawn upon a larger scale.

Each has a small head having two appendages, with tufts of hair, for sweeping small organisms and food particles into the mouth. The thorax is larger, and covered with bristles. The abdomen has nine segments, but no limbs. The eighth segment is extended into a tube, with a spiracle at the end. The ninth segment is used for swimming.

The larva cannot remain below water for any lengthy period, but must have the spiracle above the surface for breathing.

In order to return to the surface they perform a series of lashing movements (Fig. 80). The larva lasts only for a few weeks, and after three or four moults becomes a pupa (Fig. 79). This differs from the larva in having a much swollen "head," which consists of the head of the imago—with

large, compound eyes and the antennae wound round it—and also of the thorax, with wings and legs. The pupa hangs at the surface with head end uppermost, but it is by no means a quiescent stage, for if the surface of the water be disturbed it descends rapidly by a series of lashings (Fig. 80), but it soon rises again to the surface.

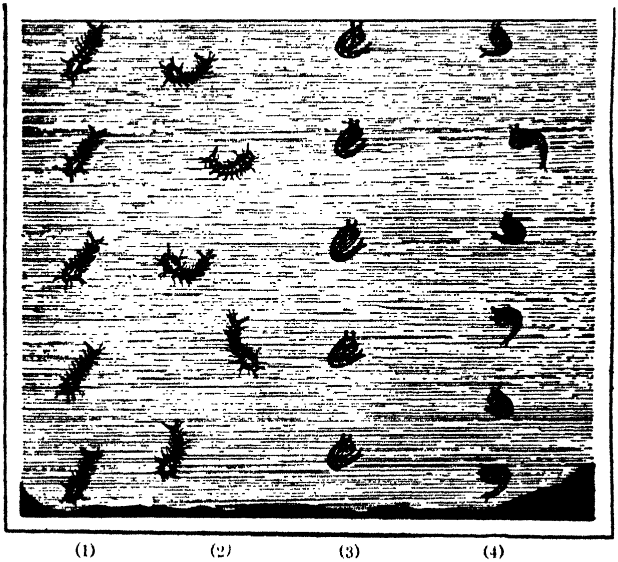


Fig. 80. DIAGRAM SHOWING MANNER OF MOVEMENT OF LARVAL AND PUPAL GNATS.

Row (1) represents the larvae descending passively; and (2) ascending actively; (3) represents the pupa rising passively; and (4) descending actively.

The larva needed its mouth in the water to obtain plenty of food, but that part of the pupa which will split to release the imago needs to be nearest the surface, and it therefore has this swollen head end uppermost; from it two breathing tubes project above the surface. When the time arrives the skin of the pupa splits, and the imago gradually and with great labour drags itself out of the case.

The gnat, like the house-fly, has only one pair of transparent wings. This character places them both in the insect order known as *Diptera*. The wings are long and narrow. The body shows the three typical divisions, and there are six legs characterised by being very long and slender (Fig. 81). The mosquito, *Anopheles*, very closely resembles the gnat, but when at rest its body is inclined upwards and its hind legs stretched straight out and not resting on the support on which it is standing. The gnat, on the other hand, either has the body parallel to the ground, or assumes rather a hunch-backed position, and its hind legs are raised with the foot joints curving upwards.

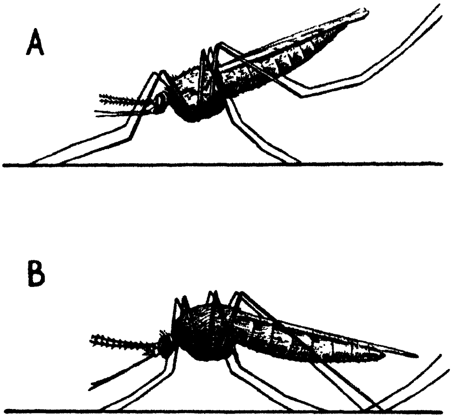


Fig. 81. A, IMAGO OF ANOPHELES; B, IMAGO OF CULEX.

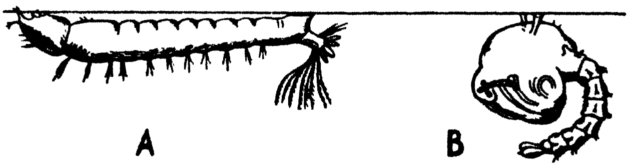


Fig. 82. ANOPHELES.
A, Larva; B, Pupa.

Fig. 82 shows the larva and pupa of the mosquito. The former lies flat along the top of the water in contrast to the gnat larva. This is because it has no spiracle tube,

but breathes through a pit on the eighth abdominal segment. The pupae are not quite so obviously different, but the breathing tubes of the mosquito pupa have square ends.

Culex and *Anopheles* resemble one another in their mouth parts, with which the females inflict such troublesome bites (Fig. 83). There are five lancets for piercing, formed by the two mandibles and the two maxillae, together with a fifth, which arises from the middle of the labrum. The mandibles have sharp, barbed tips, and the maxillae have

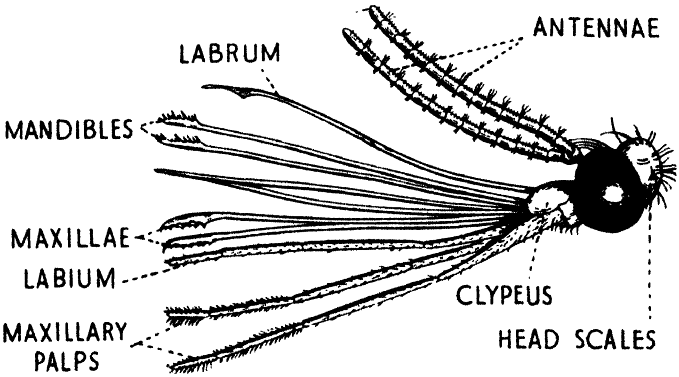


Fig. 83. Mouth Part of a Female Mosquito. (Much enlarged.)

a saw-like edge at the tip. These lancets are enclosed in the labrum and the labium. The former is a tube through which the blood is sucked after the lancets have pierced the skin. The suction is caused by the expansion of the oesophagus.

The females can be distinguished from males by the antennae, which in the male have many long hairs on each joint, so that they are like delicate feathers, while in the female the hairs are only short. The female insects lay their eggs in water. Those laid by the gnat are cemented

together to form a raft, which is in no danger of sinking (Fig. 79). The eggs have a broad and pointed end. The latter is pointing upwards, and the larva makes its way out through the broad end. The eggs of the mosquito are separate from one another. They are boat-shaped and float on the surface of the water. The eggs hatch after two or three days.

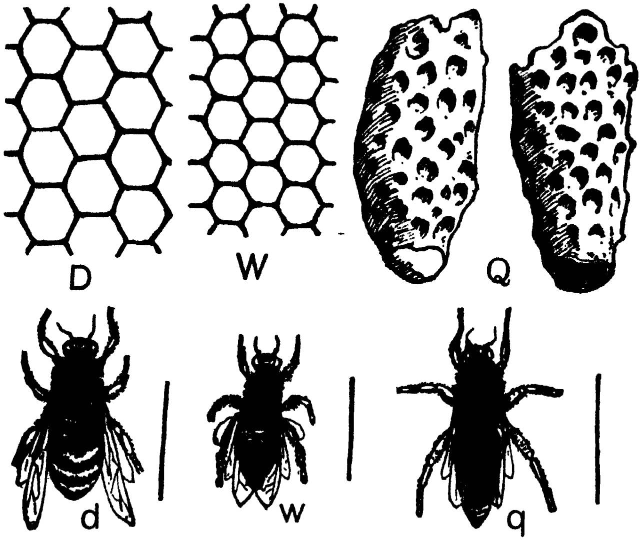


Fig. 84. BEES AND CELLS.
D, Drone cell; W, Worker cell; Q, Queen cell; d, Drone; w, Worker; q, Queen.

It is almost impossible to destroy the adult insects, but by pouring oil on to all available pieces of water, either the females can be prevented from laying their eggs, or the larvae and pupae can be suffocated.

C. THE HIVE BEE. In every bee-hive there are during the summer three kinds of bees, viz. the queen, the drones, and the workers. There is only one queen to a hive, and she may

be distinguished by her long, slender body and short wings. The drones, which are present in fair numbers, are stouter, but shorter than the queen, and their wings are longer in comparison with the length of the body. The workers are most plentiful, and are much smaller than the drones (Fig. 84).

The queen is the only functional female in the hive, and spends her entire time in laying eggs. The drones are males, and the workers are sterile females. The latter attend to the hive, construct the comb, look after the larvae which are hatched inside it, and go out to gather in food, which is stored in the hive. The drones are fat and lazy, never assisting with the work of the hive, and not even going out to gather in any food.

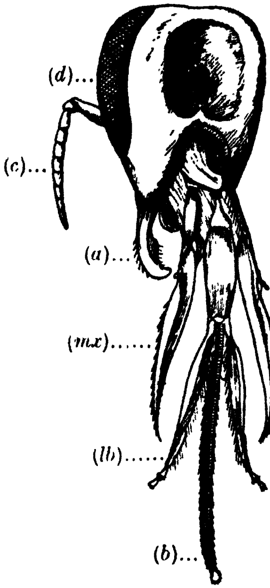


Fig. 85. HEAD OF BEE.
a, Mandibles used in moulding the cells; *b*, Lacinia of labium; *c*, Antenna; *d*, Compound eye; *mx*, Lacinia of maxilla; *lb*, Exopodite of labium.

The bee is known as a **social insect** because a large number live together in a hive. In this hive the worker-bees are the easiest to find, since they are the most plentiful, and they are also the most interesting to examine. The mouth parts are shown in Fig. 85. The mandibles (Fig. 85, *a*) are similar to those of the cockroach. The first maxillae have each only one obvious part, and this is blade-like and corresponds to the lacinia of those in cockroach (Fig. 85, *mx*). The labium has the exopodites (Fig. 85, *lb*), and the laciniae are united to form a kind of tongue, which is grooved, and along which nectar can be sucked (Fig. 85, *b*).

This ends in a spoon-like structure. On the under side of the bee's body are a number of grooves in which wax is formed in thin plates. This is then moulded with the mouth parts, shown in the figure, and used for making the cells of the hive.

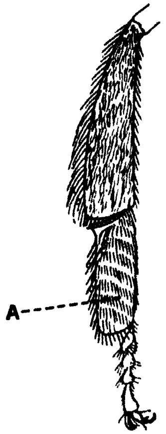


Fig. 86. PORTION OF HIND LIMB OF WORKER BEE.

A, Comb-like hairs upon tarsus for collecting pollen off body.

In addition to collecting nectar from flowers, by means of the long tongue, the worker must also collect pollen. The skin of the bee is covered with close rows of stiff hairs, so that pollen may cling readily to it (Fig. 86). These hairs on the hind legs comb the pollen from various parts of the body, and as the bee goes on its round of flower visits it collects the pollen in baskets, which are also on the hind legs. A bee which has been away from the hive for some time has on its hind legs two big, round swellings. These are the pollen baskets full of pollen. The nectar is carried back to the hive in the bee's crop, and there is made into honey.

A worker-bee must be a strong flier, but it must not have broad wings, as these would get in the way when visiting flowers, and would also interfere with the leg movements. To get over this difficulty, there are tiny hooks upon the hind pair of wings, so that, when stretched, they join on to the fore pair of wings: thus the four narrow wings make two broad ones. A worker-bee always flies swiftly and straight, hence the expression a " bee line."

A worker-bee has a sting at the posterior end of the abdomen. Inside the abdomen is a tube with backward-pointing spines which leads into a gland, containing poison (Fig. 87). When this tube is driven into anything, poison is poured along it into the wound. The backward-

pointing spines often prevent the bee from withdrawing its sting, so that it can only sting once, and may lose its life in the process. This tube corresponds to the tube with which the queen lays her eggs. She too possesses a sting, but the drones do not.

The comb is suspended vertically from the roof of the hive or built in frames provided. It consists of two layers of hexagonal cells placed back to back with the open ends slightly raised. Some of the comb cells are filled with honey and closed with a waxen lid. In other parts of the comb each cell contains an egg. It is possible to distinguish between cells containing eggs which will become workers, those which will shelter the drones, and those which will contain the larva of the new queen (Fig. 84).

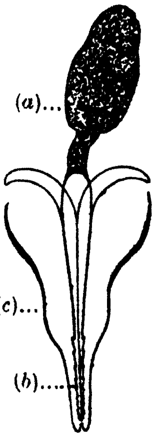


Fig. 87. Sting of Bee.

a, Poison gland; *b*, Sting which is passed into the wound; *c*, Sheath of sting, pricking.

The eggs hatch into grubs, which pupate. When they are pupae the workers seal the cells. In twenty-one days from the time of hatching the perfect insects emerge, biting their way through the cells.

There are only a few queen cells in one hive. The larvae in these are fed upon specially prepared food, called "royal jelly." The workers are fed on this for five days only, and then upon a mixture of pollen, honey and water, known as "bee bread." As soon as a queen is hatched, there is a commotion in the hive, as there must be only one queen. When this happens a fight ensues, and unless one of the queens is killed, the bees "swarm," *i.e.* the old queen leaves the hive surrounded by a band of workers to start a new hive. The new queen takes a flight during which she is fertilised by a drone, which then dies. The queen returns to the hive to lay eggs.

During the autumn when the days become cold and food scarce, the workers kill off all the drones, as they will be quite useless now that there will soon be no more new queens for them to mate with. They have done no work during the summer months, and the law is that they must not be allowed to live during the hard times of winter, on the food stored up so laboriously by other members of the community. A wasp seems to be a clever insect, but the bee has advanced still further in that it provides for the winter, so that it may live through it, and continues to use the same hive instead of having to start a new one each spring.

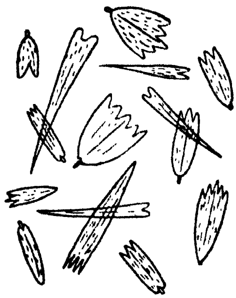


Fig. 88. SCALES FROM THE WING OF THE CABBAGE BUTTERFLY, MAGNIFIED.

" Hive-bees and bumble-bees are " social," but some species live alone or in pairs, and so are " solitary."

D. MOTHS AND BUTTERFLIES. The beautiful colouring of the wings of these insects is due to a covering of overlapping scales. If a moth's, or a butterfly's, wing is held between the fingers a powder is shed which actually consists of very tiny stalked scales, variously shaped (Fig. 88).

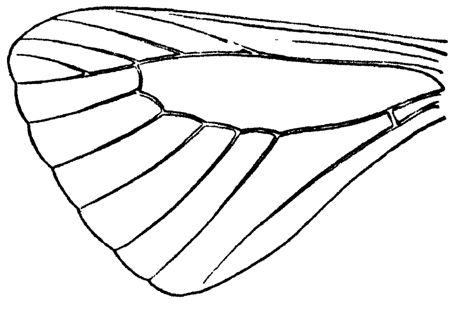


Fig. 89. DENUDED WING OF A BUTTERFLY.

If all this powder were removed the wing would be clear and transparent like a fly's wing (Fig. 89). This thin

structure is supported by rays, which are continuations of the tracheae in the moth's body. Moths and butterflies belong to the order of insects known as Lepidoptera, which means "scaly winged."

They show the body parts of a typical insect and the life-history includes three stages, a larva known as a

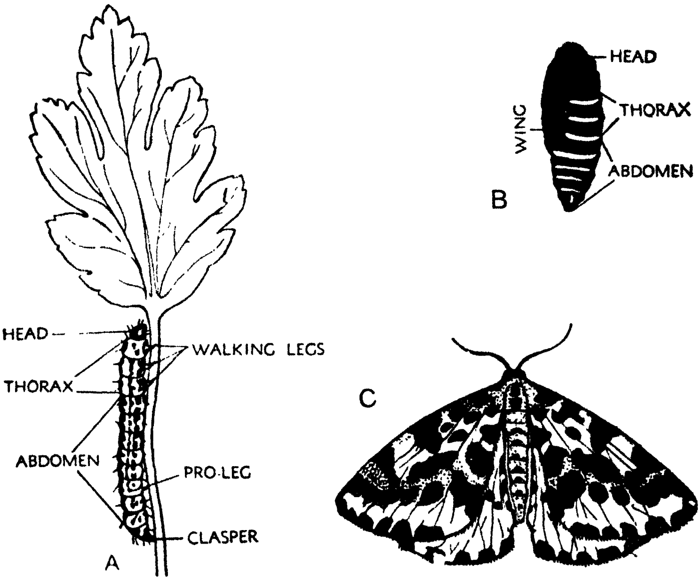


Fig. 90. THE MAGPIE MOTH.

A, Caterpillar; B, Pupa; C, Moth.

caterpillar, a pupa, and the imago. A caterpillar has a small head and long body divided into segments. On the head are several minute eyes and a pair of short antennae. The jaws protrude somewhat. The first three body segments form the thorax and on each is a pair of jointed legs. On one, or in some species, on three of the abdomen

segments are pairs of thick, unjointed pro-legs. The most posterior segment bears a pair of claspers.

The **pupa** is almost motionless. It is shorter and wider than the caterpillar and has a shell-like covering. Body segments are visible and three of them, the thorax, appear to extend only half round, because the wings, visible

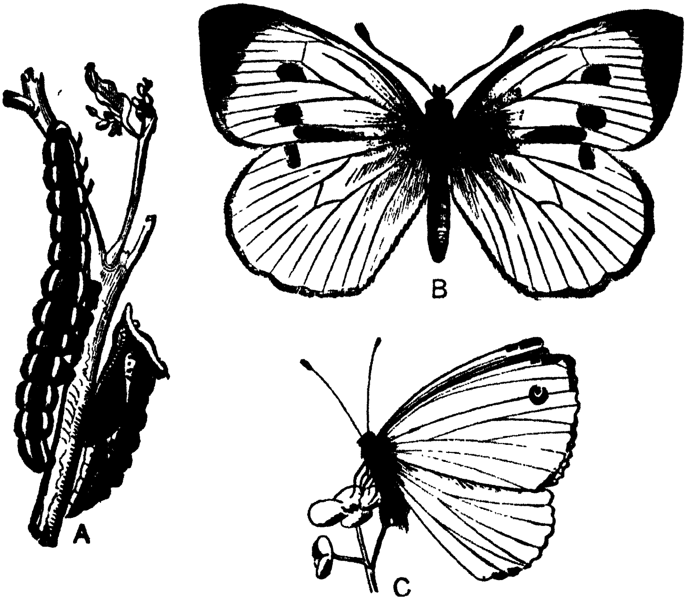


Fig. 91. The Cabbage Butterfly.
A, Caterpillar and chrysalis; B, Butterfly; C, Butterfly at rest.

beneath the shell, partly hide them. Between the outlines of the wings can be seen two long thin antennae. The pupa of a moth is frequently enclosed, together with the caterpillar's last skin, inside a silky case, called the cocoon. The pupa itself always has a smooth, rounded outline (Fig. 90). A butterfly pupa is not enclosed in a cocoon, its outline is angular (Fig. 91), and because it appears shiny and metallic it is called a chrysalis (Gk. *chrusos*, golden).

The mouth parts of the caterpillar are capable of biting, since they feed on a leaf diet, but in the imago there are no biting mouth parts, and the maxillae form a tube for sucking nectar from flowers. This so-called " tongue " is very long, especially in some moths, and in order to be tucked away, when not in use, it is coiled into a spiral. The length is needed for reaching down to the nectar at the base of the long tubes possessed by some flowers.

E. APHIDES (sing. *Aphis*).—These are the so-called " blight " that have such disfiguring effects upon some of our garden plants. Some are green, some black, and others brown. The first, which are spoken of as " green fly," occur most commonly. In spring and early summer the green flies we see are wingless females, and as soon as they are fully grown each produces a large number of female young. These develop from the egg cell of the parent although it has not been fertilised by a male cell. This phenomenon is called **parthenogenesis.** The eggs hatch before leaving the body of the parent, which is known as *vivipary.* The later offspring possess wings, and thus can fly to a new plant, the one on which its myriad relations have been produced being by now, probably, in a poor state.

At the end of the summer smaller aphides are born, and these are perfect females and males. The latter always possess wings, but the former do not. These mate, and the females lay eggs which survive the winter and hatch in spring. Ants take great care of aphides, nurturing and protecting them, because by stroking them with their feelers they obtain from them a sticky liquid which they relish. Lady-birds, on the other hand, do us great service by devouring the green fly, and in this work they are assisted by small birds, *e.g.* tits. Unless the mortality amongst the aphides were very great vegetation would be overwhelmed by them, for they are produced in incredibly large numbers.

CHAPTER VIII

THE SWAN MUSSEL

1. EXTERNAL FEATURES

There frequently occurs in rivers and large ponds, either on, or buried in, the mud, a freshwater mussel known as the **Swan Mussel** (*Anodonta cygnea*). It has a flat, dark-green shell from four to six inches long. It is oval in shape, the front end being more rounded than the posterior (Fig. 92). The shell consists of two similar pieces, or valves, which are joined together by a ligament, where the edges are almost straight. When the animal is at rest in the water the shell gapes open at the hinder end which is left projecting from the mud, and water circulates freely inside. Sometimes the mussel moves about by means of a yellowish organ, known as the **foot**, which it pushes out of the shell (Fig. 92), and by means of which it moves at the rate of about one mile a year. It feeds on very small plants, animals, and organic matter generally, which it obtains from the water. Swan mussels are sought by water-fowl, in some parts collected for pearls which may be found in the shell, and sometimes eaten by man. They are capable of withstanding very great cold, but are sometimes killed by drought.

2. DETAILED EXAMINATION

The **shell** consists of an outer horny layer, on which **lines of growth** are clearly seen. They centre round a point known as the **umbo**, situated towards the front end, which marks the position of the first shell of the young mussel (Fig. 92). Beneath this layer is a thick middle layer impregnated with salts of lime, and an inner layer composed of very thin chalky plates, known as **mother-of-pearl.**

This inner surface can be seen if the shell is wedged open with the handle of a scalpel, so that the ventral edges of the valves are about half-an-inch apart. With the shell open thus the posterior and anterior **adductor muscles** can be seen; they pass through the body from side to side and draw the valves of the shell together. The body of the mussel is seen to be very soft with a flap of tissue known as the **mantle,** which hangs down on each side covering the other organs (Fig. 93). The mantle has a thick edge which secretes the two outer layers of the shell, but the mother-of-pearl is formed by the whole of its outer surface. Should a piece of hard substance get between the mantle and the shell, the mantle secretes a layer of pearly substance round it, to render it smooth and comfortable, and this constitutes a **pearl.**

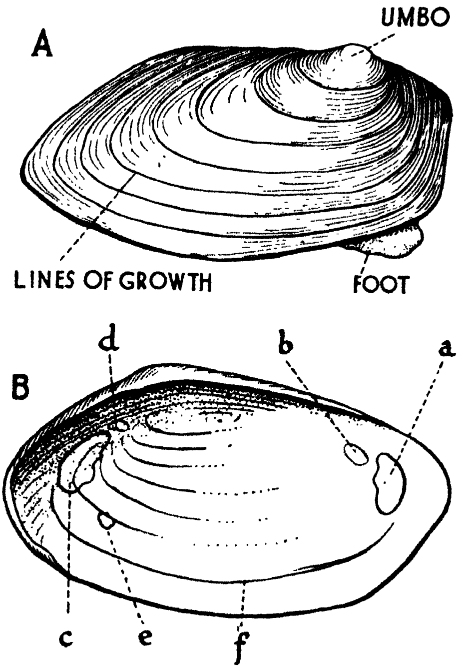


Fig. 92. SWAN MUSSEL.

A, external view; B, internal view of shell.
a, Impression of posterior adductor muscle;
b, Impression of posterior retractor muscle;
c, Impression of anterior adductor muscle;
d, Impression of anterior retractor muscle;
e, Impression of protractor muscle;
f, Pallial line.

To view the animal, detach from the left valve the anterior and then the posterior adductor muscles, using a sharp scalpel close to the shell. The valves will now gape apart owing to the action of the **ligament,** which is a strong, elastic, imperfectly calcified part of the shell which joins the valves together. It commences in front of the umbo and extends back along the straight dorsal edge of the shell, gradually widening. Bend the left valve back, cut through the ligament along the hinge line and detach the half-shell completely. On the inner side of the detached shell slight depressions can be seen in the surface where

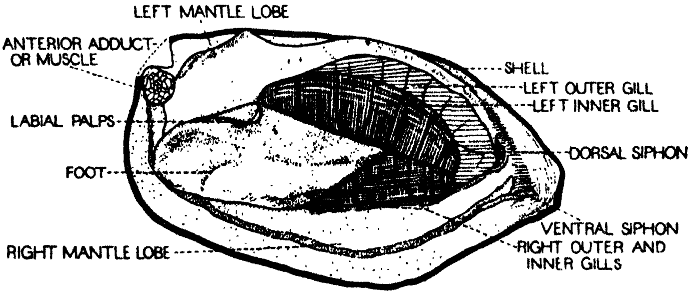


Fig. 93. Swan Mussel.
Lying in right shell with left lobe and gills turned back.

the muscles were attached, first the anterior adductor muscle, then the **anterior retractor muscle,** which draws the body forward on the foot when the latter has been thrust out. The impression of the latter muscle is smaller and attached to the posterior border of the adductor impression. A little further back is a separate impression, which is that of the **protractor muscle,** which draws the body backwards upon the foot. Near the dorsal edge and posterior end of the shell is the **posterior adductor muscle** impression, and continuous with it, the **posterior retractor muscle** impression. The paths along which these muscles have moved as the mussel grew can be traced back to the umbo. About

half-an-inch from the ventral edge of the shell, and parallel with it, is the **pallial line,** or line of attachment of the mantle.

The origin of the mantle is higher in the middle of the body than towards the two ends; while at the extreme ends it turns upwards to the hinge line. At the hind end the two mantle lobes are fused together. They then separate, and after coming close together separate again, and finally lie together for the rest of their length. Thus the form B is obtained. The lower opening is spoken of as the **ventral siphon,** and here water enters the mantle cavity, while the other is the **dorsal siphon,** where the water passes out, a continuous current of water thus entering and leaving the shell. This circulation can be watched if mussels are placed in a vessel of water with a layer of mud or sand at the bottom. The current is maintained by cilia of the mantle, gills, and palps, and brings oxygen for respiration and food for nutrition. It also carries away the waste products of both these processes, and at certain times the reproductive bodies. The lips of the ventral siphon bear a fringe of small **tentacles.**

For *dissection* leave the animal on the right valve of the shell, and fix it down on the cork under water by means of pins passed through the ligament. A small brush will clean the several parts and remove the mucus. Turn back the right mantle-lobe, as far as possible, to expose the rest of the external organs of the body. The **foot** is the most conspicuous organ revealed, being large, laterally-compressed, and oblong in shape, the lower part orange in colour, the upper part paler and softer. The orange part is a strong, muscular organ used for locomotion, being thrust out of the shell by blood being forced into it, and drawn in owing to blood being removed by the action of its muscles. The upper, soft part of the foot contains the intestine and the reproductive organs.

Lying at the sides of the upper two-thirds of the foot are the **gills.** They extend backwards beneath the

posterior adductor muscle to the end of the mantle cavity. There are two gills on each side of the body, and each consists of two **lamellae.**

Between the foot and the anterior adductor muscle is the mouth, which is bordered by two pairs of triangular folds, known as **labial palps,** which are ciliated. Each consists of two lamellae, and the surfaces which face one another are traversed by fine furrows, whose cilia work outwards. The groove between the palps leads to the mouth, and the whole forms an apparatus by means of which small organisms or particles, collected from the water by the gills, are accepted or rejected as food.

Remove the left mantle-lobe by cutting with sharp scissors along the base of the palps, round the anterior end of the gills and back along the attached base of the outer gill. The **gills** can now be seen more plainly (Fig. 90). Each consists of two lamellae, which are continuous along their ventral edges. Each lamella is composed of numerous vertical filaments, whose inner sides are fused at regular intervals, so that a ribbed plate is formed pierced by numerous openings which lead to the interlamellar gill space. The filaments of the two lamellae of one gill are continuous; and the two lamellae are connected by thick, vertical ridges, at intervals. The lamellae diverge upwards, so that in transverse section the two gills have the form W (Fig. 94). Cut edges can be examined with a pocket lens. If the lamellae are separated small pieces can be mounted and examined microscopically. The interlamellar spaces open to wider longitudinal channels known as **epibranchial spaces.** The upper border of the outer lamella of each outer gill is attached along its whole length to the inner surface of the mantle. The upper edge of its inner lamella is attached to the outer lamella of the inner gill. This junction is spoken of as the axis of the gills, and is attached to the ventral side of the body, except at its posterior end. The inner lamella of the inner gill is

attached in front of the foot, in the middle it is free, and the other end is attached to the inner gill on the opposite side. The epibranchial spaces on the right and left side of the animal, join together behind forming a **cloacal space,** which communicates with the outside by means of the dorsal

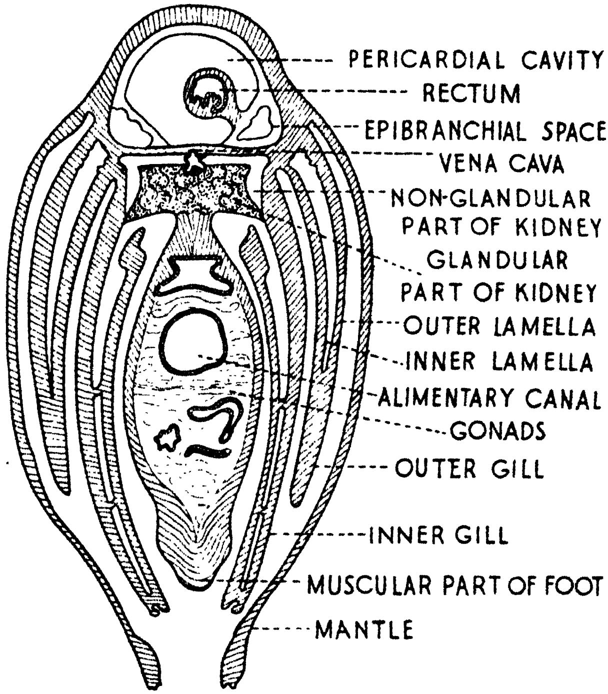


Fig. 94. Transverse Section of Swan Mussel.

siphon. The **anus,** from which the solid waste products of digestion are ejected, opens into the cloacal space. It is situated just above the posterior adductor muscle. In the female the young **embryos** remain for some time in the **outer gill,** from which they eventually enter the cloacal space and are shed through the dorsal siphon.

The surface of the gills is covered with **cilia,** by means of which a current of water, which has passed the tentacles and entered at the ventral siphon, is set up through the perforations of the lamellae into the interlamellar spaces, then to the epibranchial and cloacal spaces, and thence to the dorsal siphon. This continued supply of water brings fresh oxygen to the gills and mantle which are the **respiratory organs** of the mussel. It also brings food which passes from the gill cilia to the labial palps. The water also carries substances away, namely, the carbon dioxide produced in respiration, the **faeces** from the anus, the excretion from the kidneys, and the reproductive bodies.

Lying along the dorsal surface of the animal, ventral to the ligament, and above the bases of the gills, is an elongated space, the **pericardial cavity,** containing the **heart** (Fig. 95). This cavity is also traversed by the rectum. The walls of the cavity are transparent, so that the beating of the heart can be seen through them. Open the pericardial cavity lengthwise along the right side and cut away as much of its walls as is necessary to see the heart clearly. It will then be seen to have three chambers. The **ventricle** is placed in the median position, and is an elongated, muscular, reddish sac, which receives laterally the triangular, thin-walled, transparent sacs, the **right and left auricles.** The ventricle surrounds the rectum. The auricles collect blood from the gills and mantle lobes, and pass it through a valved aperture to the ventricle. The **blood** is colourless, containing many white corpuscles and also an organic substance containing copper, which functions like haemoglobin present in red blood, and is called **haemocyanin.** The latter becomes bluish when oxidised. The blood received by the ventricle has a rich supply of fresh oxygen, and is conveyed to all parts of the body by two main **arteries,** leaving the ventricle one at each end.

The **anterior aorta** runs forward along the dorsal surface of the rectum and supplies the foot and digestive system,

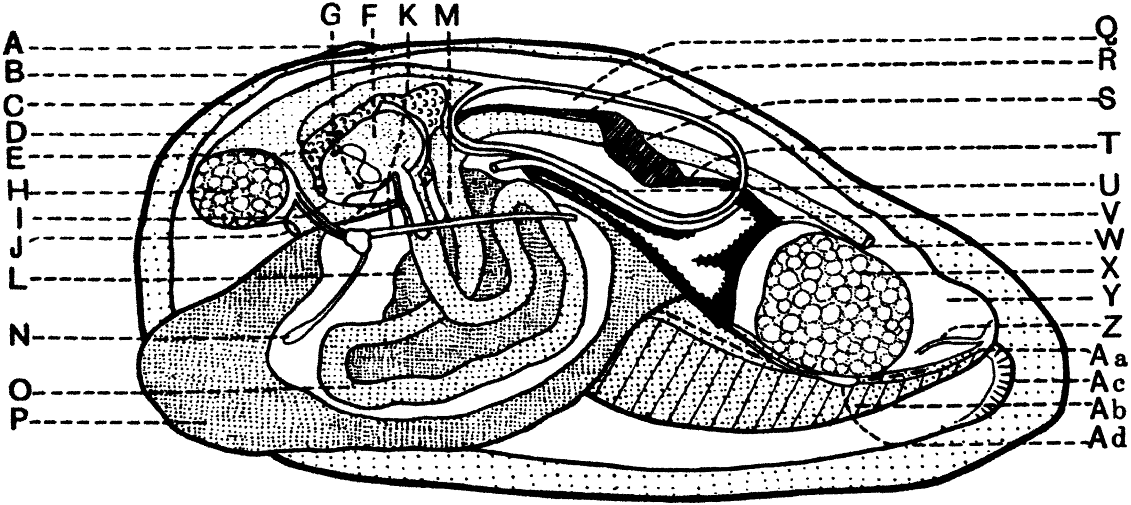


Fig. 95. DIAGRAM OF SWAN MUSSEL DISSECTION (from left side).

A, Umbo; B, Right outer shell; C, Mother-of-Pearl lining; D, Right mantle-lobe; E, Liver; F, Stomach; G, Bile duct; H, Anterior adductor muscle; I, Oesophagus; J, Mouth; K, Cerebral ganglia; L, Testes or ovary; M, Typhlosole; N, Pedal-Ganglia; O, Intestine; P, Foot; Q, Pericardial cavity; R, Anterior aorta; S, Ventricle; T, Posterior aorta; U, Ureter; V, Kidneys; W, Anus; X, Posterior adductor muscle; Y, Cloacal cavity; Z, Septum between cloacal and branchial cavity; Aa, Line of fusion of inner lamella of R. and L. gills; Ab, Right inner gill; Ac, Tentacles bordering inhalent aperture; Ad, Visceral ganglia.

while the **posterior aorta** runs backwards and supplies the rest of the body. Except the largest, the **veins** can only be seen after injection or in microscope sections. The **vena cava** is in the median, longitudinal position beneath the floor of the pericardium. This vein receives blood from the foot and digestive system, and passes it through the kidneys to the gills, via the **afferent branchial veins,** which run along the lines of attachment of the outer and inner gills. From the gills, by means of the **efferent branchial veins,** which run along the bases of the outer lamellae of the outer gills, blood is returned to the auricles. These veins also receive, at their posterior and anterior ends, vessels returning aerated blood from the mantle-lobes to the auricles.

There are two kidneys, or **organs of Bojanus,** which lie just beneath the pericardium. Each is a wide, thin-walled tube, doubled on itself, so that the ends are anterior and the loop lies against the posterior adductor muscle. The ventral limb, or **kidney proper,** has spongy walls lined with a dark, glandular epithelium. The dorsal limb, or **ureter,** is a wide, thin-walled tube which conveys the excretory products forwards to the external opening, from whence they are carried back along the branchial passages by the respiratory current to the cloacal cavity. The external aperture of the ureter is between the two lamellae of the inner gill, just in front of the place where it becomes free from the body. To find this, turn back the gills of the left side, pass one blade of a fine pair of scissors between the lamellae of the inner gill. Through the anterior end of the slit, between it and the body, cut forward horizontally through the junction of the inner and outer gills to about an eighth of an inch above this. Separate the cut edges, and brush the parts clean. The ureter aperture is small, but has rather prominent yellowish lips. Immediately beneath it is the **aperture of the genital duct.** Remove the left gill entirely, then inflate the ureter through its external

opening and slit it along its length. It will then be seen to be a wide, thin-walled passage lying above and joined to the outer side of the kidney, while its opposite side is joined to the pericardium. The vena cava lies between the two ureters, which communicate with each other by a slit-like opening near their anterior ends. The kidney opens into the front end of the pericardium by a crescentic **reno-pericardial opening.** The pericardium is really part of the body-cavity or coelom in this animal; so that here, as in the earthworm and many other animals, the kidneys are coiled tubes, with glandular walls, leading from the coelom to the exterior.

A pair of glandular bodies lie one on each side of the pericardium at its anterior end. These glands, known as **Keber's organs,** pass waste products into the pericardium. They are formed from the coelomic wall, being a part of the epithelium specialised for excretion, like the yellow cells of the earthworm.

The **nervous system** of the mussel consists of three main pairs of ganglia. They are about the size of large pin-heads, and orange in colour. They are united by nerve-connections and give off nerves to supply the various organs. The **cerebral ganglia** are situated, just beneath the skin, one on each side behind the mouth, just above the line of attachment to the mantle-lobe, and below and in front of the protractor muscle. They are connected together by a commissure which runs round the front of the mouth. They supply the fore-part of the body, and each gives off a **cerebro-pedal** connective to one of the two **pedal ganglia,** which lie side by side in the foot. To find these, split the anterior part of the foot with a scalpel in the median plane, then dissect the two halves apart until they are found. The junction between the muscular and visceral portions of the foot are clearly defined, and the ganglia lie close to it in the visceral portion. Each gives nerves to the foot and to a **statocyst,** a sense organ for

maintaining balance, which lies a little behind and below the ganglion. The **visceral ganglia** lie as a fused pair on the ventral surface of the posterior adductor muscle, at about the middle of its length, just beneath the skin. These are connected with the cerebral ganglia by the **cerebro-visceral connectives,** which run along the inner surface of the kidney.

The mouth of the mussel leads into a short, straight tube, the **oesophagus** (Fig. 95), which passes almost vertically upwards behind the anterior adductor muscle. This leads into a dilated chamber, the **stomach.** The **liver,** which is a large digestive gland, surrounds the stomach and opens into it by several **bile ducts.** The liver absorbs soluble products of digestion, and also takes up particles in an amoeboid manner. The hinder end of the stomach communicates with a closed groove of the intestine, the **caecum,** which contains a transparent, gelatinous rod, the **crystalline style.** This is composed of protein substances which project into the stomach and dissolve. It secretes a ferment for the digestion of carbohydrates. The **intestine** arises from the ventral surface of the stomach and takes several turns in the upper, soft part of the foot, spoken of as the visceral mass. It then turns upwards, and widens out, forming the **rectum,** which runs straight backwards to the anus. The ventral wall of the rectum is folded inwards to form a longitudinal ridge, the **typhlosole.** Digestion in the intestine occurs in the cells of the epithelium, and in white corpuscles which pass through this to consume food. These parts constitute the **alimentary canal** and liver, which together form the **digestive system** of the mussel. The alimentary canal can easily be followed with the help of a seeker inserted in the mouth. It should be cut lengthwise to expose the interior of the parts.

The sexes are separate, so that some mussels possess a **testis** and others an **ovary.** The generative organ surrounds the intestine in the foot, and is very large. The

spermatozoa are passed out through the dorsal siphon and they enter a female, along with the inward stream, through the ventral siphon. The eggs are fertilised in the cloacal chamber in the summer, and then pass into the outer gill, where they develop until the following spring. They are unlike the parent and are known as **glochidia,** being discharged when the water is disturbed, *e.g.* by a passing fish. Each has a shell with two triangular valves, from the apex of each of which there projects a strong hook. In place of the foot of the parent a long, sticky thread is developed. At length this thread becomes attached to small passing fish, and the glochidium is carried away from its parent. The hooks now serve to hold securely to the skin of the fish, which becomes inflamed, swells up, and encloses the little parasite, for so the little mussel has become, while its body becomes changed into the form of its parent. Later the skin of the fish which held it shrivels up and the mussel drops away to live an independent life, probably having been carried a long way from the spot where it left its parent.

A series of transverse sections is very helpful (Fig. 94). These may be obtained if a specimen be put into ½ per cent. chromic acid with the valves wedged open for two days, and then transferred to methylated spirit. Remove it completely from the shell and cut with a sharp razor.

Animals which have soft, unsegmented bodies, mantle, foot, digestive tract and nervous system comparable with those of the swan mussel are known as **Mollusca.** If their shells have two valves they are said to be bivalved, so that Anodonta may be described as a **bivalved mollusc.**

CHAPTER IX

THE DOGFISH AND SOME OTHER FISHES

1. THE DOGFISH (*Scyllium*)--EXTERNAL FEATURES

Several species of *Scyllium* are found in the sea around our coast. They are small sharks, and are closely related to skates, being characterised by having a cartilaginous, not bony, skeleton. They travel in packs, hunt by smell, and are carnivorous, devouring large quantities of crabs, shell-fish, and other small fishes. They usually live near the sea-bottom. *Scyllium canicula* is one of the commonest, and its flesh is sold as rock salmon. It has a slender body, about two feet long when well grown, grey in colour, paler on the ventral surface, and marked with dark-brown spots, which are larger and fewer in the female than male. It is whiter underneath and somewhat iridescent, so that animals below it and looking towards the light will not so easily see it. The entire body is covered with **scales,** which are directed backwards, so that they are readily felt if the animal be stroked from tail to head. Along each side of the head and body is a **lateral line,** which is much less conspicuous than in most fishes.

There is no marked difference in size along the length of the dogfish (Fig. 96), but the head, trunk, and tail can easily be recognised. The head is flat, ending in a blunt snout. On the lower side is a wide, crescent-shaped **mouth,** in front of which, and connected to it by grooves, are two **nostrils.** At the sides of the head are two slit-like **eyes,** and immediately behind each of these a small, round opening, the **spiracle.** The latter is a modified gill-cleft, and a seeker can be passed down it into the mouth. Further back is a row of five **gill-clefts,** or slits, on each side of the head

to allow water to pass out, which entered the mouth and spiracles and passed over the gills for respiration. The spiracles and gill clefts open internally into the pharynx. Rows of minute openings are arranged symmetrically on the head. Those of the **ampullary** system lead into tubes beneath the skin filled with a transparent, gelatinous substance. They are more obvious if the head is squeezed. There are also openings from **sensory** canals.

Behind the head the body becomes somewhat flattened laterally, and immediately bears the pair of largest fins, known as the **pectoral fins.** These correspond to the fore limbs of land animals. They project horizontally from the latero-ventral surface of the body. Another pair of fins, the **pelvic fins,** corresponding with the hind limbs, also occur on the ventral surface, a little in front of the middle of the body. Between these, in a longitudinal groove, is the **cloacal aperture,** which marks the end of the trunk.

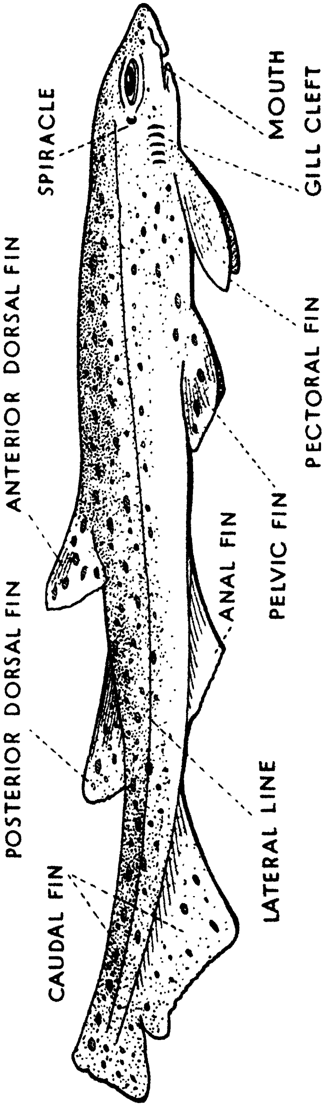


Fig. 96. Dogfish.

Into the same groove an **abdominal pore** on either side leads from the body cavity. In the male the inner borders of these fins are fused together at the hinder end, part of the fin being modified to form a **clasper,** a stout rod, grooved along its inner side, used in connection with reproduction.

The rest of the body consists of a strong, muscular tail used in swimming, which has two **dorsal fins,** the **anal fins** on the ventral surface, and ends in the **caudal fin.** The

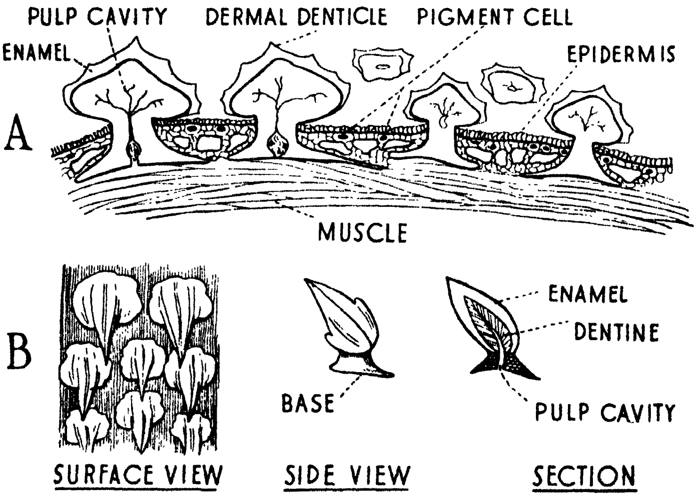


Fig. 97. Dogfish.
A, Transverse section of Skin; B, Scales of Dogfish.

caudal fin forms a vertical fringe round four or five inches of the end of the tail, the dorsal portion being narrow, the hinder end truncated, and the ventral part partially divided into two lobes.

The **scales** which cover the body are not flat like those of most fishes, but bear minute, backwardly-directed spines. They are termed **placoid.** They are special developments of the skin, consisting of a calcified basal

plate, bearing a pointed spine composed of dentine covered with enamel (Fig. 97). Each has a pulp cavity, supplied with blood vessels, and in fact resembles the structure of a tooth. They constitute part of the skeleton of the animal, known as the **exoskeleton.** If a small piece of skin be boiled for a few minutes in caustic potash the scales can be isolated, washed, and mounted in dilute glycerine for microscopic examination. If the mouth be opened several rows of **teeth** can be seen, which are really the enlarged scales of the skin which pass over the jaw. Their points are directed backwards. They lie in a groove within the jaw. As they wear away they are replaced by new ones formed by the growth of the skin.

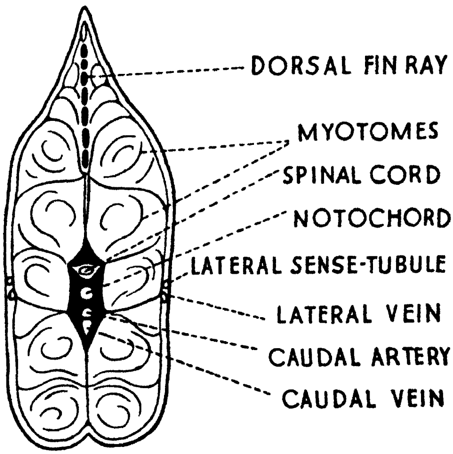


Fig. 98. Dogfish.
Transverse section through tail (partly diagrammatic).

The **endoskeleton** of the dogfish forms an important link between simpler types of animal life and those possessing a complicated bony framework. It consists almost entirely of cartilage, although it is hardened in parts by the deposition of calcareous salts. It has a **backbone** composed of about 130 parts, known as **vertebrae.** These are traversed by a central nervous system and also a rod known as the notochord. Animals which possess backbones are called **Vertebrates.**

The **muscles** are greatly developed, since the body movement assists in propelling the animal through the water. They are separated into segments, just as is the backbone of any vertebrate. These segments—called **myomeres** or **myotomes**—are each bent four times, forming a zig-zag.

A section across the tail of a fish is shown in Fig. 98. In any given section, it is possible to tell the dorsal and ventral surfaces of it, because the spinal canal with spinal cord is on the dorsal side of the vertebral column, and the haemal canal with caudal artery and vein, on the ventral side. By feeling in which direction the placoid scales point, the anterior and the posterior ends can also be determined. Every section shows parts of several myomeres because these are zig-zag. Each myomere is attached to two vertebrae, so that each vertebra is pulled by a different myomere on each side. This gives the characteristic undulating movement of the body when swimming.

2. DETAILED EXAMINATION

To dissect the dogfish lay it on its back on a board and pin it down, through the pelvic and pectoral fins with large, strong pins or awls. It is not dissected under water, although some washing is necessary. Open the abdominal cavity by a median, ventral incision from the pelvic to the pectoral girdle. These are the ridges of cartilage to which the pelvic and pectoral fins are attached. Then cut through the body wall transversely just behind the pectoral girdle, and pin the two flaps well back. Cut through the pelvic girdle to prolong the incision backwards to the level of the cloacal aperture, keeping a little to the right side.

The **coelom,** or body cavity, consists of the **pericardial cavity,** which lies just in front of the pectoral fins, and contains the heart, and the **abdominal cavity** which contains the other organs of the body. The first organ to be seen is the **liver** (Fig. 99), which is very large and yellowish in colour, consisting of a right and left lobe united in front.

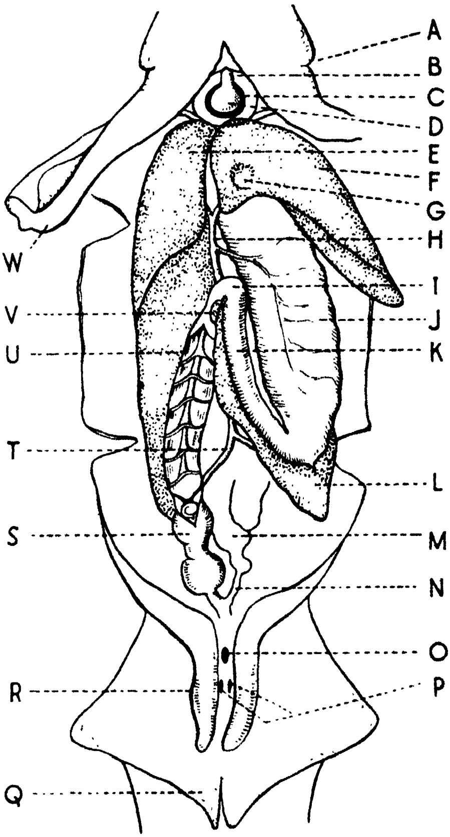


Fig. 99. DISSECTION OF MALE DOGFISH.

A, Gill-Cleft; B, Heart; C, Auricle; D, Ventricle; E, Right lobe of liver; F, Left lobe of liver; G, Position of gall-bladder; H, Bile-Duct; I, Duodenum; J, Cardiac part of stomach; K, Pyloric part of stomach; L, Spleen; M, Testes; N, rectal gland; O, Cloacal opening; P, Abdominal pores; Q, Pelvic fin; R, Clasper; S, Rectum; T, Portal vein; U, Ileum opened to show spiral valve; V, Pancreas; W, Pectoral fin.

It is attached by the falciform ligament to the anterior wall of the abdominal cavity. The liver secretes a digestive fluid, stores food, converts nitrogenous waste materials into urea to be passed to the kidneys, and is an important organ. The **stomach** is a wide U-shaped tube lying between the lobes of the liver. Attached by a membrane to the loop of the stomach, with a long, narrow prolongation along its right side is the **spleen.** Lying in the angle between the stomach and the intestine is a whitish, laterally-compressed body, about 1½ inches long, which is the **pancreas.** From its anterior end a small ventral lobe

is closely applied to the **intestine.** The latter is a wide, nearly straight tube running along the right side of the abdominal cavity from the stomach to the cloaca. The abdominal cavity is lined with a smooth membrane, the **peritoneum.** From the mid-dorsal line it becomes a double sheet which invests the alimentary canal and other organs. This is called the **mesentery,** and in it lie many of the blood vessels connected with the digestive system. It is well developed at the hinder end of the abdominal cavity, but there are several openings in it along by the intestine.

In the female, one **ovary,** containing many ova, is present, attached to the wall of the abdominal cavity by a median fold of the peritoneum. In the male the **testes** lie along the dorsal region of the anterior two-thirds of the cavity. They are a pair of whitish, solid, elongated bodies, fused at the hinder end. Two slightly elevated longitudinal ridges, extending nearly the whole length of the cavity, one on either side of the mid-dorsal line, are the **kidneys,** covered by the peritoneum.

Having located the organs it is now possible to follow the digestive tract. The mouth leads into the pharynx, which also has the openings of the spiracles and gill-clefts. The food is swallowed whole, the teeth serving chiefly to prevent escape of the prey. The pharynx leads to a short tube, the oesophagus, which expands almost at once into the stomach, where an acid digestive fluid, known as **gastric juice,** secreted by the glands of the stomach wall is poured over the food. Where the stomach joins the intestine, there is a slight constriction, accompanied by a thickening of the wall. This is the **pylorus.** Then follows a very short region, the duodenum. The intestine soon dilates into the wider part, known as the **ileum,** narrowing again at the hinder end to form the **rectum,** which leads to the cloacal aperture.

Open the intestine along its length and wash out the contents. The ileum will be seen to contain a membranous

fold running spirally round it. This is known as the **spiral valve.** The first turn of the spiral is a wide one, but the remaining seven or eight are about $\frac{1}{4}$-inch apart. It retards the passage of the food along the intestine, giving time for digestion, and increases very considerably the absorptive surface. On the outside of the ileum the blood vessels, associated with the spiral valve, can be seen. Embedded in the anterior part of the left lobe of the liver close to the median plane is a large irregular sac, the **gall-bladder.** In this is stored bile, which contains an alkaline digestive fluid, and from it the **bile duct** runs between the lobes of the liver, from which it receives other ducts. It then runs back along the ventral margin of the mesentery and along by the intestine, opening into the duodenum. The **pancreatic duct,** carrying another alkaline digestive fluid, leaves the pancreas close to its ventral border and at once enters the duodenum. It runs in the intestine wall a little way and opens just to the outside of the spiral valve. The intestine also secretes an alkaline digestive fluid to help utilise the varied kind of substance which reaches it. The undigested portion passes through the rectum and is expelled through the cloacal aperture as faeces. The walls of the alimentary canal are muscular, and the food is passed along by waves of contraction. A thick-walled tube, about $\frac{3}{4}$-in. long, dorsal to the rectum and connected to it by a small duct is the **rectal gland,** which probably excretes waste products from the blood stream.

Since the dogfish must breathe under water, the chief respiratory organs are the **gills.** The ten gill slits, five on each side, open into the pharynx. Between the slits are gill or **branchial arches,** the cartilaginous hoops from which radiate the soft, closely-set folds of membrane, known as gills. They are richly supplied with blood-vessels. The gills are borne on the posterior surface of the **hyoid arch,** which plays an important part in attaching the jaws to the skull, and on both surfaces of the first four slender, branchial

arches, the last one, the fifth, bearing no gill. The spiracle occurs between the hyoid and **mandibular** arches. The latter, from which the jaws arise, is the most anterior. The whole series of gill processes on one side of a gill arch is a **demibranch.** The spiracle appears to be an undeveloped gill slit, as it has an undeveloped demibranch on its posterior side.

A live fish in an aquarium can be seen continually opening and closing its mouth. When the mouth is open, the fish is breathing in, and water enters the pharynx through the mouth and spiracles. When the mouth closes, the size of the pharynx diminishes. The water taken in is forced over the gill processes and out through the gill slits. It does not enter the digestive tract, which remains closed except when swallowing food. Exchange of oxygen and carbon dioxide takes place through the thin, membranous covering of the gill processes which alone separates them from the blood.

The pericardial cavity should next be opened, by removing the middle portion of the pectoral girdle, to expose the heart. The cavity is median, and triangular in shape, with its apex directed forward. It lies between the gills. It is almost filled by the **heart** (Fig. 100), which is a single tube, S-shaped, dilated to form four chambers separated by transverse constrictions. These chambers from behind forwards are the thin-walled **sinus venosus,** which is transversely placed, the **auricle,** the thick-walled, globular **ventricle,** which is the most conspicuous part, and the narrow cylindrical **conus arteriosus.** The latter leads into the ventral aorta. The heart contracts from behind, thus driving the blood forward. Reflux is prevented by a valve at the opening of the sinus into the auricle, another between the auricle and the ventricle, and two rows of semilunar valves in the conus arteriosus.

The pericardial cavity is joined to the abdominal cavity by a median passage, about an inch long, dorsal to the

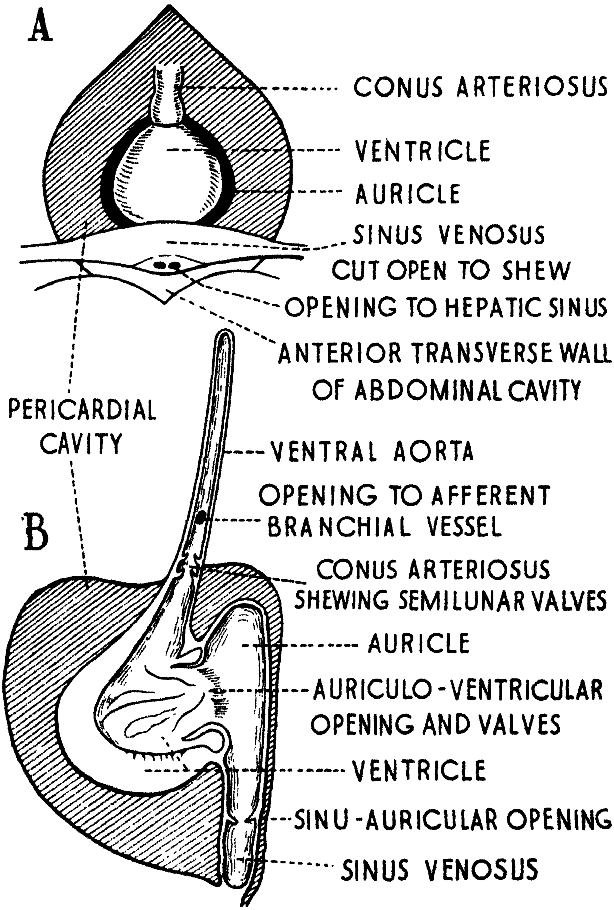


Fig. 100. THE HEART OF DOGFISH.
A, Ventral view; B, Longitudinal section.

sinus venosus, running backwards along the ventral surface of the oesophagus. This is called the **pericardio-peritoneal canal.**

The veins, which bring deoxygenated blood to the heart from all parts of the body, enter the sinus venosus. They are large with specially dilated portions, and are spoken of as **sinuses.** They can readily be traced backwards. Open the ventral wall of the sinus venosus transversely and wash out the contained blood, then follow the veins with a seeker. The **hepatic sinuses** enter by a pair of apertures in the posterior wall, close to the median plane (Fig. 101). The two wide sinuses are separated from one another by an imperfect septum, they lie ventral to the oesophagus, behind the pericardium, and lead from the liver, where they receive a large number of veins. One should be opened and followed into the liver. The rest of the blood is brought by the **Cuvierian sinuses,** which enter the sinus venosus, one on each side. They curve upwards round the oesophagus, and each receives the **inferior jugular sinus,** which, although small, can be traced forwards and inwards along the outer wall of the pericardial cavity and then forward to the floor of the mouth.

Each Cuvierian sinus also receives the **anterior cardinal sinus** by a small aperture guarded by a valve. This sinus extends forwards dorsal to the gill arches. In front of the first gill it is joined by the **post-orbital sinus,** which passes dorsal to the spiracle and below the ear, opening in front into the **orbital sinus,** which surrounds the eyeball and its muscles. The two orbital sinuses are connected by the **inter-orbital sinus,** which runs across the floor of the skull. A little farther forward the **hyoidean sinus** is received, which can be followed downward and inwards to the floor of the mouth, where it joins the inferior jugular sinus. The Cuvierian sinus also receives the **posterior cardinal sinus.** This pair of sinuses extends backwards between the body wall and the peritoneum. Posteriorly they become

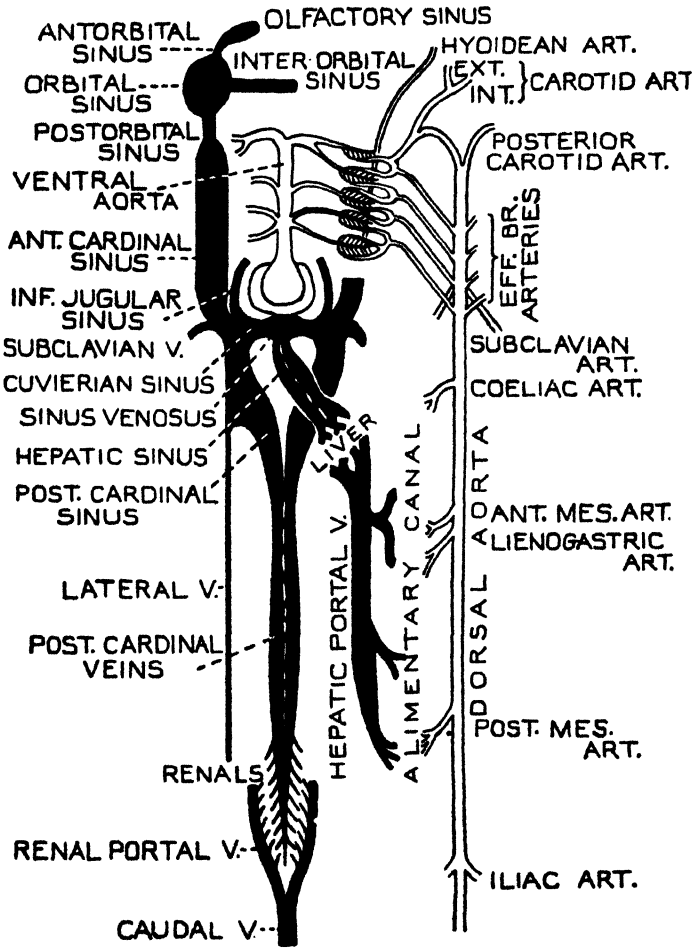


Fig. 101. Dogfish.
Blood Vascular System.

narrow and converge, communicating with one another by several connections. They traverse the abdominal cavity from between the kidneys, from which they receive blood through numerous small **renal veins.** At its anterior end each posterior cardinal sinus receives the **subclavian vein** from the pectoral fin and the neighbouring body wall. It also receives the **lateral abdominal vein,** which comes from the pelvic region and the **lateral cutaneous vein** from the tail. The blood from the muscles of the tail is returned by the **caudal vein,** which, opposite the hinder end of the kidneys, divides into the **right** and **left renal portal veins,** which receive many branches from the body wall and enter the kidneys along their whole length. A vein from the middle lobe of the spleen and one from the intestine join to make the **hepatic portal vein.** This runs forward in the mesentery, receives blood from the pancreas and stomach, and enters the liver a little to the right of the median plane.

The heart having received deoxygenated or venous blood from the veins from all over the body, pumps it out of the conus arteriosus through the **ventral aorta.** Blood which flows away from the heart is carried in arteries. The ventral aorta extends forwards for about an inch, when it gives off laterally five pairs of **afferent branchial arteries** which carry the blood to the gills, where it receives a new supply of oxygen and loses the carbon dioxide it has been collecting as it flowed round the body. These arteries can be found by making the median incision through the muscles in front of the pericardium, then parting them gently until a red, oval body, the **thyroid gland,** is found. This lies just over the anterior end of the aorta. From the fine capillaries into which the blood flowed in the gills it is collected by nine vessels, one to each demibranch, which unite into four **efferent branchial arteries.** These form a complete loop round each of four gill-clefts, the last gill cleft having no gill on its hinder border, has only one

efferent vessel on its front side, and this joins the horizontal portion of the efferent artery of the gill in front. From the dorsal ends of the loops four **efferent branchial arteries** arise, which run backwards and inwards in the roof of the pharynx, where those from the right and left sides join to make the **dorsal aorta,** which runs backwards along the whole length of the body just below the vertebral column, and becomes the **caudal artery** in the tail. From the dorsal aorta arise paired **subclavian arteries** which go to the pectoral fins. Four median arteries arise from the dorsal aorta to supply the alimentary canal, viz. the **coeliac artery,** which supplies part of the stomach, intestine, pancreas, and the liver; the **anterior mesenteric artery,** which supplies the intestine, rectum, and genital or reproductive organs; the **lieno-gastric artery** which goes to the stomach, spleen, and pancreas; the **posterior mesenteric artery,** which goes to the rectal gland. At intervals small paired **parietal arteries** arise to supply the body wall. A pair also supply the pelvic fins, and these are known as the **iliac arteries.** From the dorsal end of the efferent branchial vessel of each hyoidean gill arises the **carotid artery.** This runs forwards and, opposite the hinder border of the orbit, divides into the **external carotid artery** which supplies the upper jaw and snout, and the **internal carotid artery** which supplies the cranial cavity. The internal carotid artery joins with the **hyoidean artery,** which arises from the anterior limb of the first loop of the efferent branchial vessels and together they supply the brain.

A **blood** slide should be prepared (*see* Appendix). The blood consists of a colourless fluid, or **plasma,** in which numerous **red corpuscles** and a small number of **white corpuscles** float freely. The latter are small, granular, and exhibit amoeboid movements. The red corpuscles are flattened, oval discs with rounded edges, and a central swelling due to the presence of a nucleus, as in frog (Fig. 121). The colour is due to the presence of haemoglobin.

The functional **kidneys** or posterior mesonephros are situated in the posterior part of the body cavity, and are covered by peritoneum; further details differ in the two sexes. In the male, several ducts from the kidney join a common duct called the **ureter** which opens, like its fellow of the opposite side, into a median **urinogenital sinus.** This sinus then opens into the cloaca on the **urinogenital papilla.** From the posterior mesonephros is a large continuation towards the front of the abdominal cavity; this continuation is called the anterior **mesonephros, or epididymis,** and visible on its surface is a much convoluted tube, the **vas deferens** which is continuous with the mass of tubules and connective tissue of which the mesonephros is composed. The anterior mesonephros has therefore become part of the male genital system, and its tubules are

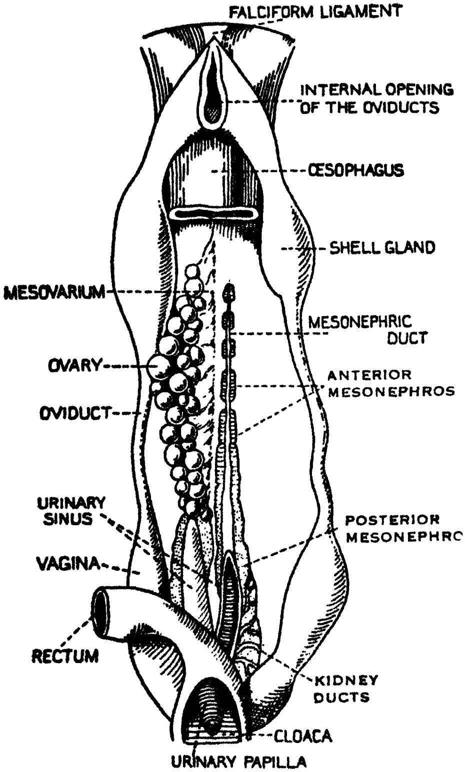


Fig. 102. Dogfish.
The Renal-Reproductive System (Female).

connected with those of the testis by ducts known as the **vasa efferentia.** Posteriorly the vas deferens enlarges into a wider tube called the **vesicula seminalis,** which opens into the urinogenital sinus. Into this sinus also open a pair of so-called **sperm sacs**, the function of which is not clear.

In the female, the anterior mesonephros is vestigial, but there are the mesonephric ducts of each side which open individually into a **urinary sinus** which is the widened end of the mesonephric duct (Wolffian duct); the two urinary sinuses are purely urinary and not urinogenital as in the male. They unite posteriorly and open into the cloaca on the urinary papilla (Fig. 102). The single **ovary** is about 2 or 3 inches long and the heavily yolked ova, when developed, are about half-an-inch in diameter. The **ova** enter the oviducts from the abdominal cavity, just in front of the liver where the two ducts have united. Each oviduct forms a thick-walled gland which secretes horny capsules round the eggs (Fig. 103). Two eggs are laid at a time, one from each oviduct. The capsules are oblong, brown, and about 2 or 3 inches long when laid, and the embryos can safely develop within them. Long thin strands hang from the four corners, which serve to anchor the eggs to seaweed. The empty cases, when they are found on the shore, are often called mermaids' purses. The posterior ends of the oviduct unite and open by a median aperture into the cloaca, immediately behind the rectum.

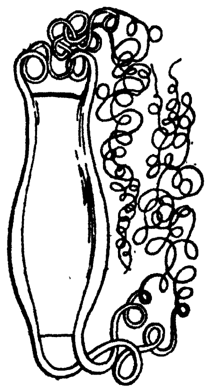


Fig. 103. Egg-Case of Dogfish.

In the male the testes are a pair of elongated, yellowish bodies slung from the dorsal body wall in a sheet of peritoneum, the mesorchium. Their genital products, the spermatozoa, pass from them to the cloaca via the vasa

efferentia, the epididymes, vasa deferentia, vesiculae seminales, and urinogenital sinus (Fig. 104). When expelled, they are conveyed by the tubular claspers to the female cloaca and oviducts. Anterior to the claspers, immediately beneath the skin lies a sac called the **siphon.** It leads by two tapering prolongations, resembling ducts, to the grooves of the claspers. It may take in water and help in the discharge of sperms. The **spermatozoa** are delicate, thread-like bodies with a thickened middle piece round which is a spiral membrane.

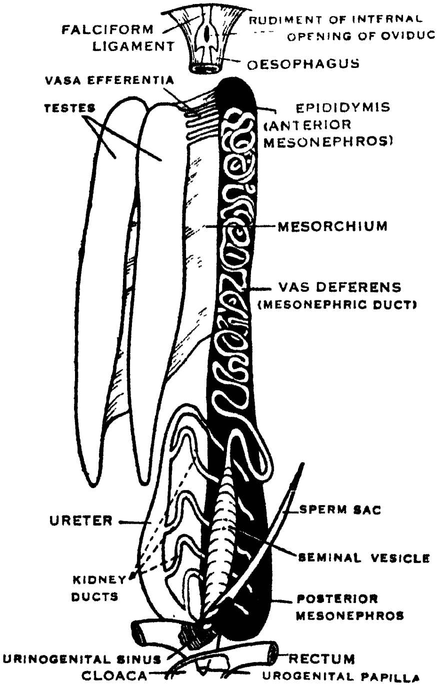


Fig. 104. Dogfish.
Male Reproductive Organs. (After Leigh-Sharpe.)

For the dissection of the **nervous system** a dogfish should have the roof of the skull removed to admit spirit to harden the brain. The nervous system consists of (*a*) a central portion, the brain, contained within the cranium, and the spinal cord in the neural canal of the backbone, or vertebral column; and (*b*) a peripheral portion, the nerves, which connect the central part with all parts of the body. To find the **brain** remove the skin from the dorsal surface of the head, dissect away the

eyelids on the right side and open the orbit, then cut away the roof of the cranium until the brain is fully exposed.

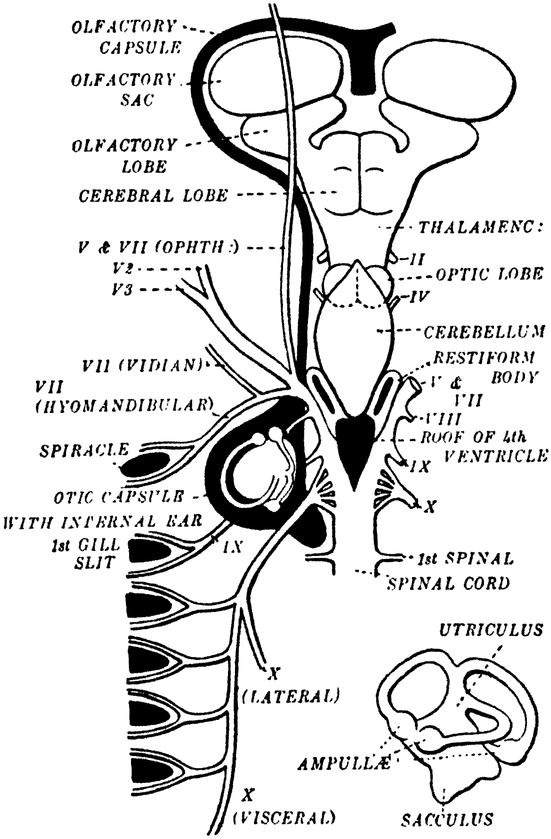


Fig. 105. DOGFISH.
Brain, Cranial Nerves, and Auditory Organ. [*Vidian* = *Palatine.*]

It will be necessary to cut through the auditory capsule. Looked at from above, the brain consists of the **prosencephalon,** which is anterior, smooth, and globular, with a

shallow median groove. It is often called the cerebrum or cerebral lobes as in higher animals (Fig. 105). The **olfactory lobes** are a pair of large oval masses borne on stalks. The **thalamencephalon** is the narrow portion behind the prosencephalon, and the **third ventricle** or cavity of the brain, which is more or less hollow, can be seen through its roof, which consists of a membrane traversed by numerous blood vessels and called the **choroid plexus.** From the hinder part of the thalamencephalon arises **the pineal body,** a slender, tubular body, which ends in a dilated knob attached to the membranous roof of the skull in front of the brain. The **optic lobes** lie in the narrowest part of the cranial cavity, their posterior halves are overlapped by the **cerebellum,** which is a long, flattened,

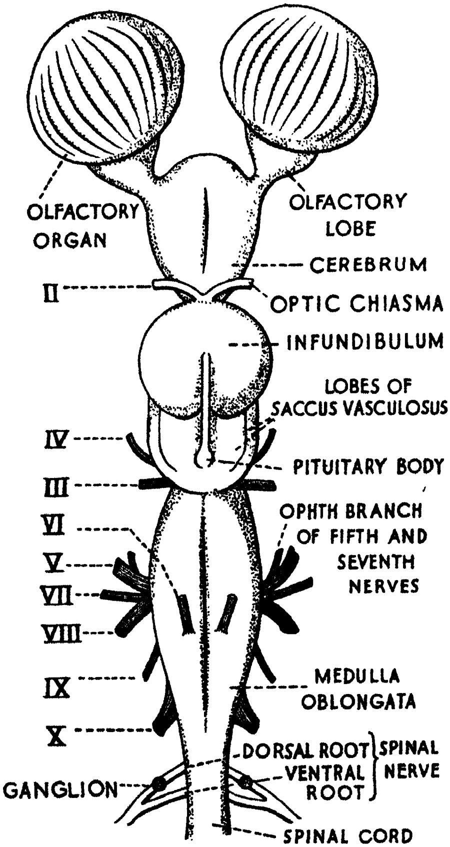


Fig. 106. Dogfish.
Ventral view of Brain.

oval body. Behind this and overlapped by it, is the **medulla oblongata,** and through the thin roof here can be seen the fourth ventricle. From the sides of this arise the Vth, VIIth, and VIIIth cerebral nerves. Above these is a pair of wing-like **restiform bodies.**

The nerves should be dissected before the brain is removed, and if the nerves are dissected on one side of the head, the sense-organs can be dissected on the other.

Ten pairs of **cranial nerves** arise from the brain (Figs. 105, 106). Some are motor, since they cause muscular movement, others are sensory, supplying a faculty, *e.g.* sight.

Name of Nerve Pair	Organs Supplied	Type of Action
I. Olfactory	Nose	Sensory
II. Optic	Eye	,,
III. Oculomotor	Eye muscles	Motor
IV. Trochlear or Patheticus	,, muscle	,,
V. Trigeminal branches into:		
(1) *ophthalmic*	Skin of snout	Sensory
(2) *maxillary*	Upper jaw	,,
(3) *mandibular*	Lower jaw	Sensory and motor
VI. Abducens	Eye muscle	Motor
VII. Facial branches into:		
(1) *ophthalmic*	Skin of snout	Sensory
(2) *buccal*	Sense organs (neuromasts) of sides of face	,,
(3) *palatine*	Roof of mouth	,,
(4) *hyomandibular*	Hyoid arch, lower jaw, neuromasts of hyomandibular region	Sensory and motor
VIII. Auditory	Ear	Sensory
IX. Glossopharyngeal	1st branchial and hyoid arches	Motor and sensory
X. Vagus branches into:		
(1) *lateral line branch*	Lateral line	Sensory
(2) *branchial*	Branchial arches 2-5	Sensory and motor
(3) *visceral*	Viscera	,, ,, ,,

In dissecting the nerves the ophthalmic branches of the Vth and VIIth nerves are easily found. The olfactory nerves arise from the anterior surface of the olfactory lobe as two large bundles and pass through the sieve-like membrane separating the cranial cavity from the nose. At the extreme front end of the brain a paired pre-olfactory nerve arises. The olfactory nerves should be dissected from the dorsal side. The course of the optic nerve within the skull can be seen when the brain is removed. In the orbit the branches of the IIIrd nerve can easily be dissected from above. To see the origin of the IVth nerve, lift up the front end of the cerebellum and look between it and the optic lobe. The Vth, VIIth, and VIIIth arise close together from the side of the medulla, and will be found if the medulla is pressed away from the skull wall. The latter and the auditory capsule should be cut away to expose the nerve roots fully. Turn the eye up to trace the ophthalmic nerve across the floor of the orbit. The VIth nerve arises from the ventral surface of the medulla, but to see the part of it within the skull the roots of the Vth and VIIth must be cut through and the brain pressed aside. The VIIth arises from the dorsal edge of the medulla, immediately behind the cerebellum. Cut the auditory capsule down to the level of the root of the VIIIth and trace the nerve into it. The IXth arises from the side of the medulla just behind the VIIIth. The pneumogastric, or vagus, is a large nerve arising by a number of roots from the side of the hinder part of the medulla.

The **brain** should now be removed by cutting across the medulla a little behind the roots of the vagus, and then cutting through the several cranial nerves midway between the brain and skull-wall. The ventral surface can now be examined. In addition to the parts seen from the dorsal side, on the under surface of the thalamencephalon (Fig. 106) will be seen the **optic chiasma.** This is formed where the two optic nerves cross and fuse. In spite of the

crossing, part of each nerve proceeds to the eye on the side on which it arises. Immediately behind the optic chiasma are two oval swellings, the **infundibulum,** which is produced posteriorly into a pouch, the **saccus vasculosus.** Lying between the lobes of the infundibulum is the **pituitary body,** a small glandular mass which was attached also to the floor of the skull.

If the brain be bisected in the median plane, the following cavities can be seen:—the **lateral ventricles** in the prosencephalon, which open into the cavity of the thalamencephalon and the olfactory lobes; the **third ventricle** which is a cavity within the thalamencephalon, connecting with the lateral ventricles, the pineal body, the optic lobes and infundibulum; the saccus vasculosus, optic lobes, cerebellum, and restiform bodies are all hollow; the **fourth ventricle** which lies in the medulla.

The small size of the prosencephalon, or cerebral portion, as well as the nature of the cells composing it suggest that the dogfish has little memory or ability to learn, while the large size of the cerebellum corresponds with the great muscular activity needed in swimming and keeping its equilibrium.

The fibres of the brain continue into the **spinal cord,** so that the former has control over all movement due to the spinal nerves. The spinal cord lies in the neural canal of the vertebral column, and is flattened dorso-ventrally. It is traversed by a narrow **central canal** continuous with the fourth ventricle of the brain. There is a pair of **spinal nerves** for each vertebra, and each nerve has two roots, a dorsal, sensory root, and a ventral, motor one. The dorsal ganglionated root arises in front of the corresponding ventral one and passes out from the neural canal through a notch in the hinder border of the intervertebral plate (Fig. 108). The ventral root has three or more rootlets and passes out through a smaller notch in the hinder border of the vertebral plate. The two roots unite outside the vertebral column to form the spinal nerve (Fig. 106).

The **nose** of a fish has no connection with respiration, but only with the sense of smell. In the dogfish the olfactory organs are a pair of spheroidal sacs with a very large number of vertical laminae projecting into the cavity from the dorsal side. They are large and well developed.

The **eye** shows the typical structure (*see* Chapter XIII.).

The **ear** consists only of the internal ear and is much reduced from the hearing organ of the land animals (*see* Chapter XIII.). To the dogfish it is particularly an organ of balance. The utriculus and sacculus are only feebly indicated (Fig. 105). The semicircular canals are well developed. The endolymph contains calcareous otoliths. The **aqueductus vestibuli** connects the ear with the water.

THE SKELETON.—The backbone, or **vertebral column,** consists of trunk and tail vertebrae. A trunk vertebra has a **centrum** traversed by a **notochord,** a **neural arch** surrounding the spinal cord, and transverse or **haemal processes.** In the tail vertebrae the latter unite ventrally to form a canal which encloses the caudal artery and vein. The centra are short cylinders of cartilage connected by bands of strong tissue, which allow slight movement between the successive vertebrae and free bending of the whole backbone. Each centrum has deep concavities at its posterior and anteriod ends, that is, is bi-concave (Fig. 107), and the notochord is constricted at the centre of each vertebra. The notochord is more usually an embryonic structure, which serves as a firm basis for muscle attachment, and usually precedes the formation of cartilage, but in dogfish the notochord is present all through life. From each centrum a pair of

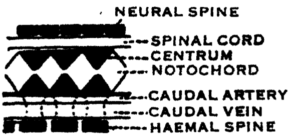


Fig. 107. DOGFISH. Median Longitudinal section of Three Caudal Vertebrae.

neural plates form the sides of the neural arch, but as these are shorter than the centra **intervertebral neural**

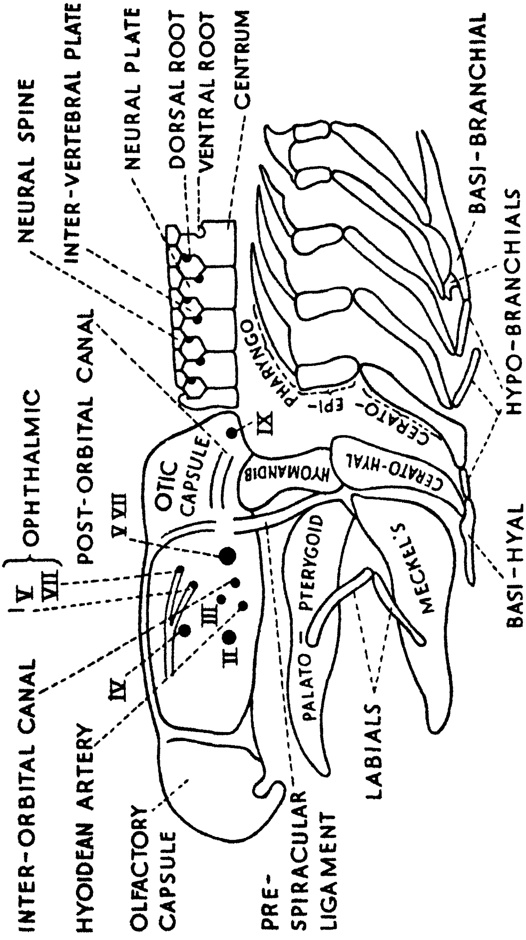


Fig. 108. Dogfish.
Skull, Visceral Arches, and Part of Vertebral Column.
(Modified from Marshall and Hurst.)

plates come between them. The arch is completed by a double series of **neural spines** which alternate with the plates (Fig. 108).

In the anterior part short transverse processes arise ventro-laterally, to which short, cartilaginous **ribs** are movably attached. Further back, these processes project ventrally as haemal processes, causing the under surface of the column to be grooved, and in the tail they unite, forming the **haemal arch,** and are produced to form the **haemal spines.**

For the support of the median fins, there are cartilaginous **fin-rays** in continuation with the neural spines.

The **skull** consists of the **cranium** proper, which contains the brain, and the **olfactory** and **auditory sense capsules,** together with a series of visceral arches (Fig. 109). The skull is a somewhat oblong box, deeply hollowed at the sides to form the orbits, and ending in a short, pointed **rostrum** formed by three converging rods. At the junction of the cranium and nasal capsules there is a large gap in the roof of the skull, the **anterior fontanelle.** The orbits are protected above and below by the **supra-** and **sub-orbital ridges.** A median depression on the roof communicates on each side with a canal carrying the aqueductus vestibuli from the ear. Numerous openings pierce the wall of the skull to admit the nerves and the blood vessels; these are spoken of as **foramina.** At the posterior end is a large median hole, the **foramen magnum,** through which the spinal cord enters. The notochord joins the skull immediately below, and a pair of prominences at its sides, known as **condyles,** articulate with the first vertebra.

The upper jaw is supported by a bar, the **palato-pterygoid cartilage,** the lower jaw by **Meckel's cartilage,** and the jaws are joined to the skull by a large cartilage, the **hyomandibular cartilage,** behind the spiracle. This is joined to the hyoid arch, the remainder of which consists of a **cerato-hyal** on either side and a ventral **basi-hyal.** The former is long and slender and runs forwards into the floor of the mouth, bearing the gill-rays on its posterior border. The basi-hyal is perforated by the thyroid gland. Behind there are the five branchial arches supporting the walls of the

pharynx, each composed of four segments which are named from the dorsal side downwards, **pharyngo-, epi-,**

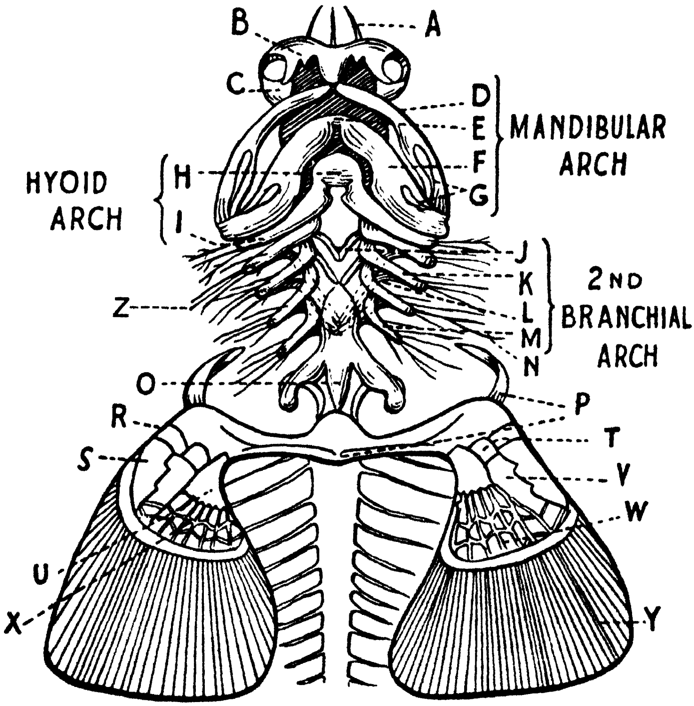


Fig. 109. Skull and Pectoral Girdle of Dogfish.

A, Rostrum; B, Nasal cartilage; C, Olfactory capsule; D, Upper jaw; E, Ligament; F, Lower jaw; G, Labial cartilage (Mandibular Arch); H, Basihyal; I, Ceratohyal (Hyoidean Arch); J, Hypo-branchial; K, Cerato-branchial; L, Epi-branchial; M, Pharyngo-branchial (Second Branchial Arch); N, Extra Branchial; O, Basi Branchial; P, Pectoral girdle; R, Pro-pterygium; S, Pro-pterygial fin-ray; T, Meso-pterygium; U, Meta-pterygium; V, Meso-pterygial fin-ray; W, Polygonal cartilage plate; X, Meta-pterygial fin-ray; Y, Horny fibres; Z, Gill-ray.

cerato-, hypo-branchials, and a median **basi-branchial** in the floor of the pharynx. Three pairs of slender curved

rods lie along the sides and beneath the second, third and fourth branchial arches, and two pairs in the folds of the skin at the sides of the mouth.

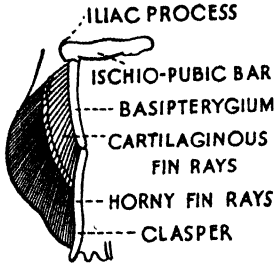


Fig. 110. Dogfish.
Pelvic Girdle and Right Pelvic Fin. (After Marshall and Hurst.)

The **pelvic fins** are attached to the **pelvic girdle** (Fig. 110). This is a nearly straight rod, placed transversely across the body, about half-an-inch in front of the cloaca. The fins are attached to blunt processes at the ends of the girdle. Each fin consists of a slightly curved basal rod along the inner side and attached to the girdle, this is the **basi-pterigium,** which in the male is produced into the claspers. From the outer side of this a series of parallel **radial cartilages** run outwards and backwards, supporting at their ends smaller polygonal plates. Beyond these are a number of **horny fibres** derived from the skin. Some of the radial cartilages may connect with the girdle directly.

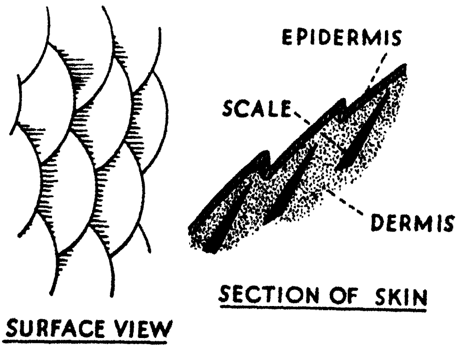


Fig. 111. Scales of Whiting.

The **pectoral fins** (Fig. 109), are attached to the **pectoral girdle,** which lies immediately behind the last branchial arch. This girdle is larger than the pelvic and is a hoop incomplete above. The ventral portion is produced forwards to form part of the floor of

the pericardial cavity and is hollowed dorsally to receive the ventricle of the heart. At each side the arch bears a triple articular facet for the basal cartilages of the fin. These are the **pro-**, **meso-**, and **meta-pterygium.** The last is the largest and extends along the inner border of the fin, bearing all the radial cartilages except two, which are borne one each by the pro- and meso-pterygium. Polygonal plates and horny fibres are present as in the pelvic fins.

The **dorsal fins** have similar parts. The basal ends of the radial rods here frequently unite.

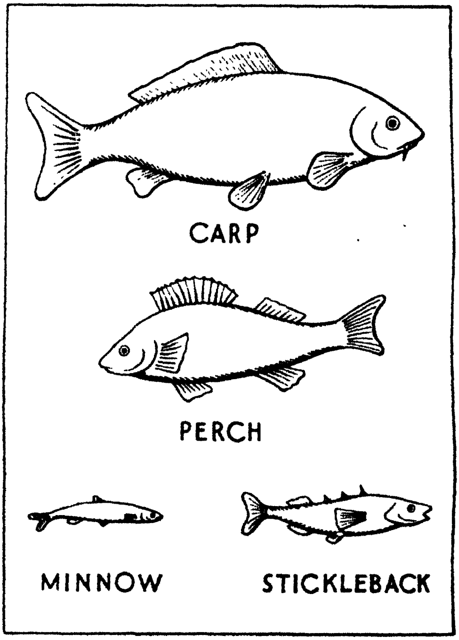


Fig. 112. Fresh-Water Fishes.

3. BONY FISHES

Most of the fish with which we are familiar are bony fish. They are plentiful in fresh as well as salt water. Goldfish may be kept quite easily and their habits watched, their respiratory movements and those of their tail and fins. These fish are covered with thin, rounded **scales** (Fig. 111), which are bony in nature and covered with skin. They overlap backwards to facilitate the forward movement of the fish in the water.

The openings of the gill clefts are covered by a bone-supported flap, the **operculum.** The gill clefts lead straight outwards through the sides of the throat, so that the arches are narrow. There is no spiracle.

These fishes have an **air-bladder** in the abdominal cavity, which adds considerably to their buoyancy. The anal, genital, and urinary openings are separate in a shallow, ventral depression. The jaws also have teeth. The nostrils are paired and they have no internal openings. They have no eyelids. The tail is symmetrical in appearance. The dorsal and ventral fins vary in number, size, and position (Fig. 112).

Whiting (*Gadus merlangus*), haddock (*Gadus anglefinus*), and cod (*Gadus morrhua*) have their pelvic fins shifted forwards so that they lie in front of the pectorals. Plaice and soles resemble whiting but they are flattened from side to side. They therefore lie on one side from which the eye has moved, a twist in the skull having brought this to the upper side. The upper side is coloured to resemble sand and pebbles because these flat fish live near the bottom of the water. They are thus less visible to their enemies.

The bony fishes differ from the dogfish in their reproductive system; their hard and soft roes are familiar. The soft roes contain the spermatozoa and the hard roes contain hundreds or, in some cases, thousands of minute eggs. These eggs are laid, usually with very little protection, and take their chance of life. They eventually hatch into an enormous number of baby fish, which for some time will remain more or less together and make a shoal of fish of that particular kind. Many will be consumed by larger hungry fish during their young lives, but as is well known, many survive.

CHAPTER X

THE FROG

1. EXTERNAL APPEARANCE

The generic name of the frog is *Rana*, and our British frog, *R. temporaria*, has received its specific name from the presence of a dark brown patch in the region of the temples, immediately behind each eye (Fig. 113). The ground colour of the skin is yellowish. It is spotted and streaked with brown, but the most prominent marks are bars on the hind limbs. The general colour of the skin varies according to the frog's surroundings, which it tends to match, thus rendering the animal less visible to its enemies. The skin is perfectly smooth and always moist.

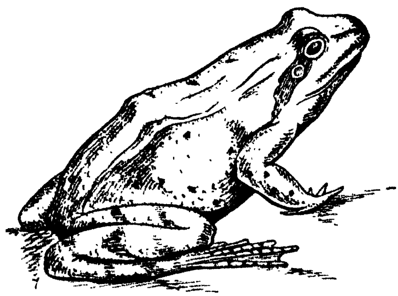


Fig. 113. FROG. *Rana temporaria.*

During the winter frogs hibernate, buried in the mud at the bottom of ponds or in damp holes. When they are awakened to activity again they spend their time amongst long grass, in the hedges, amongst the dense undergrowth in a wood, and similar damp situations. The body is divided into head and trunk, but there is no neck; the head gradually widens out towards the body. Attached to the trunk are two pairs of limbs, a front pair and a hind pair. These correspond in position, but not in function, to the paired pectoral and pelvic fins of a fish. Their structure is very different from that of a fin. Each

has three distinct regions, upper arm, forearm, and hand in the front limbs, and thigh, shank, and foot in the hind limbs. There are four fingers to the fore limbs and five toes to the hind limbs (Figs. 113 and 116). The five toes are connected by a thin web. The frog is an expert swimmer, partly owing to the webbed feet, which act as oars, and partly to the shape of the body, which is widest at the middle and narrows at the two ends, so that it is somewhat boat-shaped. There is no tail, the animal being propelled through the water entirely by the movements of the two powerful hind limbs. The hind limbs are very much longer than the front. When the frog is in its normal resting position the hind legs are bent, but when stretched out their length becomes obvious (Fig. 113). The great length of these limbs enables the animal to take long leaps.

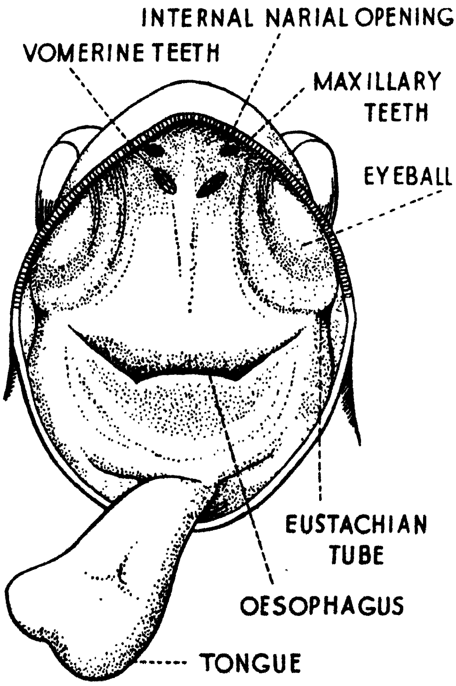


Fig. 114. FROG.
Open mouth.

The large **mouth** extends right round the front and sides of the head. On the dorsal surface of the head and near the front are a pair of holes, the **nostrils**, or external

nares. The **eyes** have an immovable upper lid and a very thin lower lid which is capable of moving right across the eye, completely covering it. This movable lid corresponds to a third eyelid, which is present in a bird and behaves in the same way. Just behind and somewhat below each eye there is a shallow, circular hollow, and this is the **ear drum**, or tympanic membrane.

If the mouth of a dead frog be opened and the inside examined, there can be seen round the edge of the upper jaw a row of fine teeth, called **maxillary teeth**, and in the front part of the roof of the mouth two small patches of **vomerine teeth** (Fig. 114). There are no teeth on the lower jaw. The frog's food is swallowed whole and the teeth

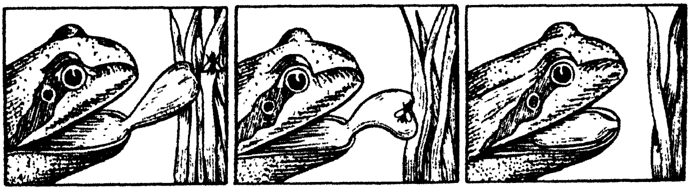


Fig. 115. FROG.
Mouth, showing the use of the tongue.

possibly help to prevent slippery prey from escaping. As the teeth wear out they are replaced by new ones. A very evident structure is the large **tongue**, attached to the floor of the mouth near the front, and having its tip pointing backwards towards the throat (Fig. 115). It is distinctly sticky. Near the vomerine teeth are two small holes, the **internal nares.** Bristles passed through the external nares emerge into the mouth through the internal nares. On the floor of the mouth, one in about the middle of each side, are two more openings, **Eustachian tubes**, leading to the ear drums. Between the internal nares and the Eustachian tubes are two large bulges caused by the eye-balls. The **pharynx** or throat, which leads to the alimentary canal, has in the floor a narrow slit, the **glottis**, leading to the lungs.

The glottis opens into a **larynx**, or voice box containing two vocal cords. The male has a pair of vocal sacs which are formed by the wall of the pharynx and which are inflated when in use. The female has no vocal sacs and croaks less loudly in consequence. It is possible to distinguish between a male and a female frog because the former is smaller. The male also has on the first finger a pad.

2. DISSECTION

To place the frog ready for dissection, stretch it out on its back and secure by means of a pin through each limb. Cut through the skin along the middle line and continue the cut along each leg to the knee, then pin back the flaps of skin. A male frog can be dissected under water, but for a female frog it is better to use normal salt solution (·75 per cent.) to prevent the eggs from swelling too much. Cut through the body wall on each side of the middle line, continuing the cut through the bony pectoral girdle in the front. The middle strip of body wall that remains has in it a blood vessel which must therefore be ligatured before it can be cut, to prevent blood escaping from the vessel. Tie cotton round it very tightly in two places fairly close together and cut between these two ligatures. The flaps can then be turned back (Fig. 116).

A frog is killed by leaving it for about fifteen minutes in a stoppered bottle containing chloroform vapour, and if it is dissected at once the **heart** will be seen to be still beating. It is surrounded by a transparent membrane, the **pericardium**, and if this is cut away the beat can be seen more plainly. The anterior part of the heart consists of two parts or **auricles**, and the more pointed posterior part is the **ventricle.** A cylindrical chamber arises from the ventricle and runs across the auricles; this is the **truncus arteriosus** (Fig. 118). Lift up the ventricle and turn the point forwards; a triangular portion on the dorsal surface of the heart is thus brought into view. This is

area of the stomach. If the duodenum is cut along the right side, the bile duct is seen opening into it, and bile may be squeezed along from the gall bladder.

Other organs present deal with the waste materials produced in digestion. This is one of the functions of the liver. Close to the beginning of the large intestine there is a round, dark-red body, the **spleen.** This helps to convert nitrogenous waste into a form suitable for removal from the body and also destroys worn-out red blood corpuscles. Lying beneath the alimentary canal there are two flat, oval **kidneys.** These filter out of the blood urea produced in the liver, and surplus water and mineral salts. These waste products form urine. A white tube, the urinogenital duct, arises from the outer edge of each kidney and runs into the cloaca. In a male frog the urinogenital duct carries reproductive cells as well as urine, and there is a swelling close to the cloaca, called the **vesicula seminalis,** in which the reproductive cells are stored. The **bladder** is very thin and bilobed. If a kidney is examined, on its ventral surface a yellowish-red patch, the **adrenal body,** is seen. The adrenals and the spleen are ductless glands. (See Chapter XIV.) Other ductless glands in the frog are (1) the **thyroids,** a pair of round, pink bodies in the throat region; (2) the **thymus,** consisting of a pair of yellow bodies above the angle of the jaw on each side. The functions of these glands are given in Chapter XIV.

There are also present a pair of bright yellow tufts, **fat bodies.** These are usually in close connection with the reproductive organs, which consist in the male of a pair of yellow, oval testes ventral to each kidney to which they are connected by a number of fine tubes, vasa efferentia.

On each side of the heart and covered over by the liver is a **lung.** Each is pink and somewhat spongy-looking, and opens on the glottis.

The whole of the alimentary canal is, as it were, hung in the body cavity, or coelom, by a very thin sheet, called the

mesentery. This sheet is really a fold from the **peritoneum,** the membrane lining the body cavity. A membrane called the **pleura** forms two coverings, one for each lung. The membrane round the heart is called the **pericardium.**

The **blood vascular system** consists of heart, veins, arteries, and capillaries. In order to follow it in a dissection it is necessary to remove the alimentary canal by cutting through oesophagus, large intestine, and mesentery. The heart acts as a pump, veins carry blood to it, and arteries away from it, and capillaries form networks of very fine vessels joining veins and arteries to one another. Arteries contain blood under pressure because it is pumped into them from the heart. They have thick, elastic walls, with much unstriped muscle. The arteries are distended with each heart-beat, but the elasticity of their walls restores their original size, causing the pulse, felt by pressing an artery against a bone. This elasticity combined with muscular contraction can also cause alteration in the size of the diameter of an artery. The narrow diameter and increased area of the capillaries lessens the rate of flow of the blood, so that when it leaves these it flows evenly in the veins, the walls of which are thin and scarcely elastic.

In a dead animal veins are larger than arteries, which are at their narrowest diameter now the heart is out of action. Because the blood shows more through their thinner walls veins are darker in colour than arteries, and as they are nearer the surface they should be dissected first. In dissecting it is necessary to clear away with forceps and scalpel the tissue surrounding each vein. This should be done along, and not across, the veins, and great care taken not to prick the veins themselves. Dissection is performed more easily if the parts are pinned out so as to stretch the veins slightly.

The three main veins, venae cavae, open into the sinus venosus. Two of these, the **right and left anterior venae cavae,** correspond to one another. If one of these is traced forward it is found to be formed by (1) the **external jugular**;

giving it its looseness. The lymph after bathing the tissues is collected from the lymph spaces into lymphatic vessels, and is eventually returned to the blood vascular system.

Lymph is also contained in the lacteals, a set of vessels which receive from the small intestine the digested fats. (See Chapter XXIV.) This lymph enters a sac between the ventral surface of the backbone and the peritoneum, the **subvertebral lymph sac** (Fig. 122). The lymph must eventually reach the blood again, and for this purpose the lymph vessels in the shoulder region are connected with the subscapular veins on each side, and those in the posterior part of the body are connected with the femoral veins. In both these places are a pair of **lymph hearts**, sacs which pulsate and therefore force the lymph into the blood vessels.

Breathing in a frog is accomplished by means of the **skin** as well as the lungs. For this reason the skin must always be moist, as gases cannot pass through a dry skin. Thus if the skin becomes dry the frog is in danger of suffocation.

A transverse section of the skin is shown in Fig. 123. It consists of an outer layer, the **epidermis**, which has an outer horny layer of dead cells, occasionally shed whole and entire. The inner layer of living cells is the Malpighian layer. (See Chapter XII.) Under this is the living **dermis**, consisting of connective tissue. (See Chapter XII.) Immediately under the epidermis are cells containing colouring matter, and in the connective tissue are glands, some of which secrete mucus to keep the skin moist. Others secrete a watery liquid with an unpleasant taste.

The **lungs** open into the pharynx, at the back of the mouth cavity, by means of the glottis. Each is an oval bag of which the internal surface is increased somewhat by ingrowths from it into the inside of the lung. The pulmonary artery divides into capillaries on reaching the lung, as do the arteries on reaching any organ. In these capillaries the walls are very thin and oxygen passes through them from the lung to the blood contained in them, while

carbon dioxide passes out. The capillaries unite to form the pulmonary vein which carries this oxygenated blood to the heart, whence it is pumped over the body. The pulmonary artery differs from all other arteries in containing deoxygenated blood, and the pulmonary vein from all other veins in containing oxygenated blood.

Air is forced into and expelled from the lungs by the action of the nares and a flat plate of cartilage, called the

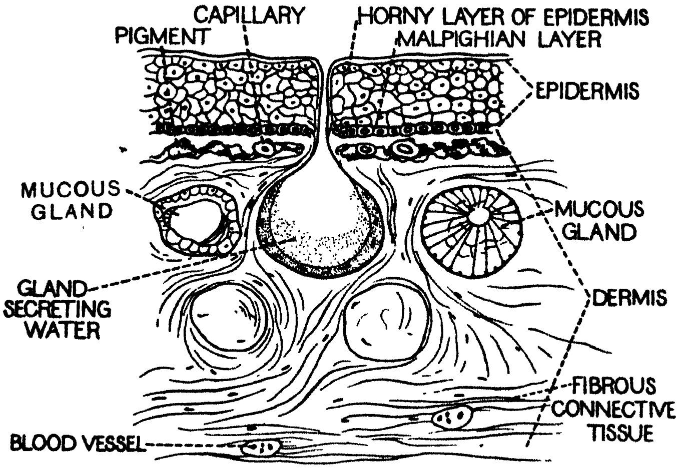


Fig. 123. Frog.
Transverse Section of Skin (highly magnified).

hyoid, on the floor of the mouth. This is connected by one set of muscles with the shoulder girdle and by another with the skull. The breathing movements of the frog consist of the upward and downward movement of the throat caused by the movement of the hyoid. When the frog breathes in, the nares are open, and the muscles connecting the hyoid to the shoulder girdle contract, pulling the hyoid down and back. This enlarges the cavity of the mouth and air rushes in through the nares. The nares then close,

and by the contraction of the muscles connecting the hyoid to the skull, the hyoid is raised so that some air must be forced out of the mouth. The only passage for it is into the lungs. Breathing out is due to the lungs contracting, partly because they are elastic and partly owing to the pressure of the viscera on them. This causes air to be expelled through the nares immediately they are opened. While the frog is hibernating respiration takes place entirely through the skin.

The **nervous system** consists of a central nervous system and a sympathetic nervous system. The latter supplies nerves for the blood system and the viscera. The former consists of brain and spinal cord with the nerves arising from them, which form the peripheral nervous system.

The brain is inside the skull, and the cord inside the backbone; these must therefore be partly cut away to expose them. The **spinal nerves** are, however, outside the backbone, and can be dissected by cleaning them in the same way as veins and arteries. They are ten pairs of white cords on either side of the backbone. Where each nerve comes from the backbone a white chalky mass occurs. Immediately beyond this chalky mass each nerve divides into two, a short dorsal branch, passing to the back, and a long ventral branch. The backbone consists of nine separate bones or vertebrae, and the first pair of spinal nerves, called the **hypoglossals,** leave the backbone between the first and second vertebrae. They run forward to the tongue (Fig. 124). Next posterior on each side is a **brachial plexus** consisting of (1) the second spinal nerve, (2) branches from the hypoglossal, (3) a branch from the third spinal. This plexus forms the brachial nerve, which gives off a branch to the shoulder, runs down the arm, and divides into two above the elbow for the lower part of the arm. The fourth, fifth, and sixth pairs of spinal nerves supply the muscles and skin of the body wall. A **sciatic plexus** is formed on each side by the

seventh, eighth, and ninth nerves. This gives off branches to the large intestine, bladder, and reproductive organs, and forms the sciatic nerve which runs into the leg, dividing into two above the knee. Before they join the plexus, the seventh nerves give off (1) **ileo-hypogastric** which goes to muscles and skin of abdomen; (2) **crural** to muscles and skin of thigh. The tenth pair, called **coccygeal,** give branches to the bladder and cloaca, and one to the sciatic nerve.

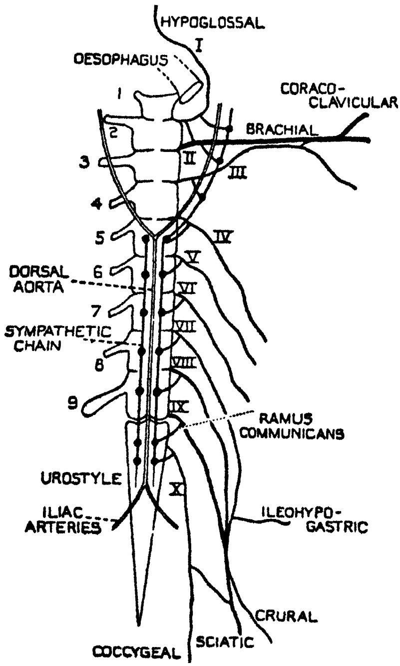


Fig. 124. FROG.
Spinal and Sympathetic Nerves.

The **sympathetic nervous system** consists of two cords, one on each side of the backbone and ventral to it. Each spinal nerve gives off a branch to the cord on the same side as itself, and where each of these branches joins the cord is a swelling, or ganglion. From these ganglia nerves are given off to the blood vessels, alimentary canal, etc. These nerves given off from the first ganglion form the cardiac plexus, a network of nerves on the heart and around the vessels opening into it. There is another similar network on the stomach, called the solar plexus and formed by nerves from third, fourth, and fifth ganglia. Similar plexuses occur in connection with the liver, kidneys, reproductive organs, large intestine, and bladder.

It is now necessary to cut away the skull and backbone to expose the brain and **spinal cord.** First expose the latter. From the dorsal surface of the frog cut away a strip of the skin and the body wall about half-an-inch wide down the middle of the back, beginning at the base of the skull and continuing to the posterior end of the body. Do this in order to lay bare the backbone.

Hold the frog, dorsal side up, with the head pointing towards you. Insert one blade of the scissors into one side of the first vertebra, keeping the blade flat and parallel with the back of the frog. Cut through the bone on this side and then insert the blade in the other side and cut through it there. Proceed in the same way for each vertebra, thus removing the dorsal part of every one. The spinal cord is now exposed, and it can be seen as a thickish white structure tapering off to a fine point posteriorly. Each spinal nerve has a dorsal and a ventral root, but these soon join. The dorsal root has on it, before it joins the ventral one, a swelling or ganglion, which may be hidden by the chalky masses already noted. The anterior nerves pass out transversely from the spinal cord, but the middle and posterior pass obliquely backwards before leaving the backbone. The most posterior nerves pass backwards inside the backbone for some distance; these roots within the backbone, together with the thin end of the spinal cord, the **filum terminale,** are called the **cauda equina.**

To remove the roof of the skull, hold the frog with the nose pointing away from you and bent slightly down. Between the base of the skull and the backbone there is a tough membrane. Cut this through and insert one blade of the scissors with the flat surface parallel to the back of the frog. Keeping the scissors as close to the roof as possible, cut through the side walls of the skull first on one side and then on the other. Turn the roof of the skull forward with the forceps and remove it entirely. Before

extracting the brain and the spinal cord it is advisable to keep the frog in strong spirit to harden them.

From the **brain** arise pairs of cranial nerves. There is one pair from the front which pass to the nose. Cut through these; then hold the frog vertically with the head up. Lift the front of the brain with a scalpel and allow it to fall, by reason of its own weight, from the skull. Cut through the cranial nerves on both sides as far from

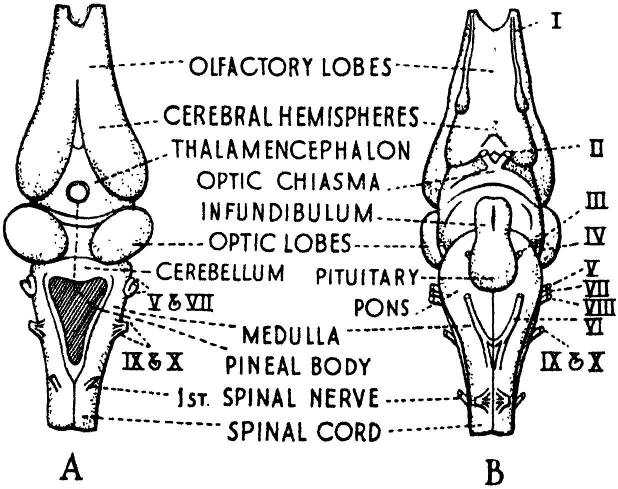


Fig. 125. Brain of Frog.
A, Dorsal; B, Ventral view. (After Wiedersheim.)

the brain as possible, so that the whole brain will gradually fall out. To extract the spinal cord pass a scalpel down each side to cut the roots of the spinal nerves. Lift it with a scalpel, or let it fall out, pulling the thin terminal part out gently. The brain and cord should be put into spirit in order to examine them.

The brain is covered by a thin membrane with spots of dark pigment in it, the **pia mater**, which can be removed. On examining the dorsal surface of the brain (Fig. 125, A)

from before backwards the following parts can be seen: at the anterior end the **olfactory lobes,** which are united together in the median plane; separated from them by slight constrictions are a pair of smooth, ovoid bodies, the **cerebral hemispheres**; behind these and between their diverging portions is a lozenge-shaped part, the **thalamencephalon,** which is covered by a membrane, the **choroid plexus**; then there is a pair of prominent ovoid bodies, the **optic lobes,** touching each other in the median plane; immediately behind these is a narrow transverse band, the **cerebellum**; and behind this again the **medulla oblongata** (covered by a triangular choroid plexus), which gradually tapers towards its posterior end, where it is continuous with the spinal cord. Immediately above the thalamencephalon is the stalk of the **pineal body,** which may have been torn away with the roof of the skull. The pineal body may perhaps represent a third eye, possessed by some remote ancestor of the frog, and the stalk would be the nerve of that eye.

If the brain be carefully removed and the ventral surface examined, certain additional parts will be seen (Fig. 125, B). Opposite the posterior ends of the cerebral hemispheres is the **optic chiasma,** resembling an X, where the optic nerves cross. These nerves can be traced from behind their point of crossing to the optic lobes. Situated behind the optic chiasma is a swelling arising from the floor of the thalamencephalon, known as the **infundibulum.** A flattened ovoid sac, the **pituitary body,** or hypophysis, is attached to the infundibulum; it may, however, have been left behind in the skull when the brain was removed. Two dense white masses of nervous matter, lying at the base of the optic lobes, connect the cerebral hemispheres with the medulla; these are the **crura cerebri.** A distinct ventral groove in the hinder part of the brain is continuous with the ventral groove of the spinal cord. It is from this side particularly that the cranial nerves can be seen.

The brain is frequently considered to have three regions: the **hind-brain,** consisting of the medulla oblongata and the cerebellum, the **mid-brain,** consisting of the crura cerebri and the optic lobes, and the **fore-brain,** consisting of the thalamencephalon and the cerebral hemispheres. There are ten pairs of **cranial nerves** numbered from the anterior to the posterior. The first are (1) the **olfactory,** supplying the nostrils, and these are the only pair arising from the

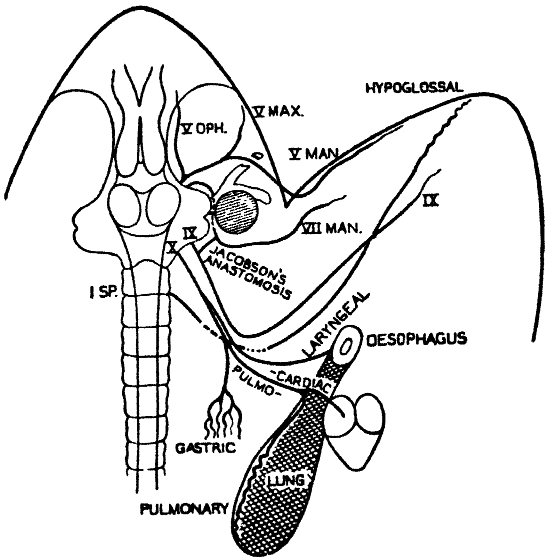


Fig. 126. Cranial Nerves of the Frog.

fore-brain. The next three pairs, arising from the mid-brain, are as follows: (2) **optic,** supplying sense of sight; (3) **oculo-motor,** supplying four of the muscles that move the eyeball; (4) **trochlear,** supplying another eyeball muscle. The remaining nerves arise from the medulla as follows: (5) **trigeminal,** which divide into three branches supplying the skin of the front part of the head, the upper jaw and

lower jaw; (6) **abducens** supply the eye muscles on each side; (7) **facial** supply mucous membrane of roof of mouth, muscles of hyoid and lower jaw; (8) **auditory,** the nerves of hearing; (9) **glossopharyngeal** supply some muscles on the floor of the mouth and mucous membrane of pharynx and tongue; (10) **pneumogastric or vagus.** The last pair of nerves are often called the wanderers because they take a very long journey to larynx, heart, lungs, and stomach. The distribution of some of these nerves on one side is represented diagrammatically in Fig. 126. Notice how the glossopharyngeal and vagus cross the first spinal nerve, the hypoglossal, which runs to the tongue. Some of the cranial nerves cause movement, and are therefore motor, and others supply a sense organ and are sensory. The following table summarises the nerves together with some of their branches and their work.

Name of Nerve Pair	**Organs Supplied**	**Type of Action**
I. Olfactory	Nose	Sensory
II. Optic	Eye	,,
III. Oculomotor	Eye muscle	Motor
IV. Trochlear	,, ,,	,,
V. Trigeminal branches into:		
(1) *ophthalmic*	Skin of front of head	Sensory
(2) *maxillary*	Upper jaw	Motor
(3) *mandibular*	Lower jaw	,,
VI. Abducens	Eye muscle	,,
VII. Facial branches into:		
(1) *palatine*	Mucous membrane of roof of mouth	Sensory
(2) *hyoidean*	Muscles of hyoid	Motor
(3) *mandibular*	Muscles of lower jaw	,,
VIII. Auditory	Ear	Sensory
IX. Glossopharyngeal	Muscles of lower jaw	Motor
	Mucous membrane of pharynx and tongue	Sensory
X. Vagus	Larynx, heart, stomach, lung	Motor and sensory

In a transverse section of the spinal cord (Fig. 194), there is a tiny hole in the centre. A cavity called the central canal traverses the length of the cord and is closed at its posterior end. This cavity is continuous with the ventricles of the brain. These may be discovered by slicing off the upper surface (Fig. 127). The cavities in it are called ventricles. There are a pair of **lateral ventricles,** one in each cerebral hemisphere and extending into the olfactory lobes. These communicate by the **foramen of Monro** with the **third ventricle** in the thalamencephalon. The **fourth ventricle** is a large triangular one in the medulla, which is covered only by a thin membrane. A narrow passage, the **aqueduct of Sylvius,** leads from the third to the fourth ventricle. The ventricles of the optic lobes open into it from above.

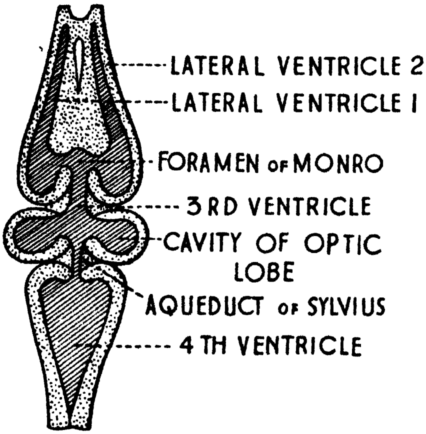


Fig. 127. Horizontal Section of Brain of Frog.

The whole body is supported by a bony framework, **the skeleton,** which forms an attachment for the muscles of the body which constitute the flesh. Fig. 128 shows the entire skeleton. It consists of (1) an axial part formed by the skull, and backbone; (2) an appendicular part formed by the limb girdles with the limbs attached. The skeleton of the embryo consists of cartilage which mostly becomes replaced by bone, although some cartilage remains in the skull. Bone which replaces cartilage is called cartilage-bone, and that

which develops independently of cartilage is called membrane bone. The only membrane bones in the frog's skeleton are some in the skull and the collar bones.

THE VERTEBRAL COLUMN.—The backbone, or vertebral column, consists of nine **vertebrae** and a long posterior portion, the urostyle. The dorsal parts of the vertebrae

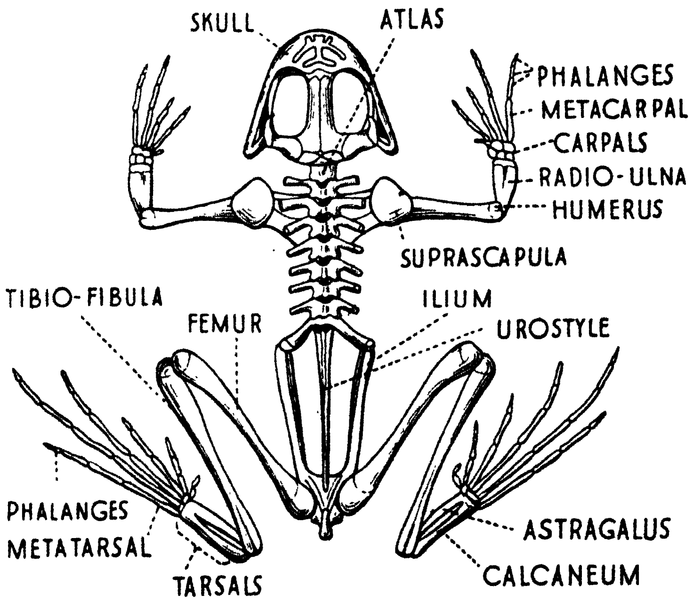


Fig. 128. SKELETON OF FROG.

form an arch through which passes the spinal cord. The first, eighth, and ninth vertebrae have special peculiarities, but all are built on the same general plan.

Each consists of a ventral portion, the **centrum**, and a dorsal arched portion, the **neural arch** (Fig. 129). These enclose a space, the **neural canal**, for the spinal cord. Projecting from the centre of the neural arch there

is a **neural spine,** which points upwards and backwards. From the points of union of the centrum and neural arch a pair of **transverse processes** (absent in the first vertebra) project horizontally. These all have a pad of cartilage at the end. There is a pair of projections on the anterior surface and another on the posterior surface of the neural arch, known as the **prezygapophyses** (absent in the first vertebra) and **postzygapophyses** respectively. The former face upwards and slightly inwards and the latter downwards and slightly outwards. The prezygapophyses of one vertebra articulate with the postzygapophyses of the vertebra in front, and they slide over one another as the

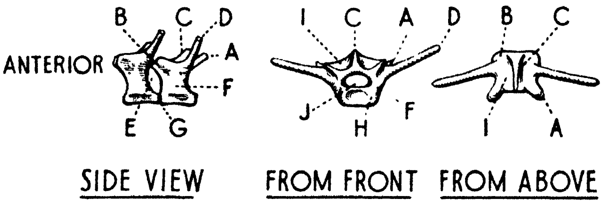


Fig. 129. VERTEBRAE.
A, Postzygapophyses; B, Prezygapophyses; C, Neural spine; D, Transverse process; E, Intervertebral foramen; F, Pedicle; G, Ball and socket; H, Centrum; I, Lamina; J, Neural canal.

backbone bends. The majority of the centra are hollow in front and rounded behind so that they fit together by ball and socket joints. The first verbetra, however, the **atlas,** has in front two hollows which receive two knobs, the occipital condyles, on the base of the skull. The centrum of the eighth ventebra is hollow behind as well as in front; but that of the ninth is rounded in front, in order to fit into the eighth, and has two knobs behind, which fit into two hollows on the urostyle. The transverse processes of the ninth vertebra are greatly enlarged and are attached to the long bones, the ilia, of the hip girdle. The **urostyle** is about the same length as the

vertebrae put together; on its dorsal surface it has a ridge and tapers posteriorly. Between the vertebrae, on each side of the backbone, is a tiny hole, an intervertebral foramen, through which the spinal nerves pass out. At the sides of the urostyle and about the length of a vertebra from its anterior surface are a pair of holes which correspond to intervertebral foramina.

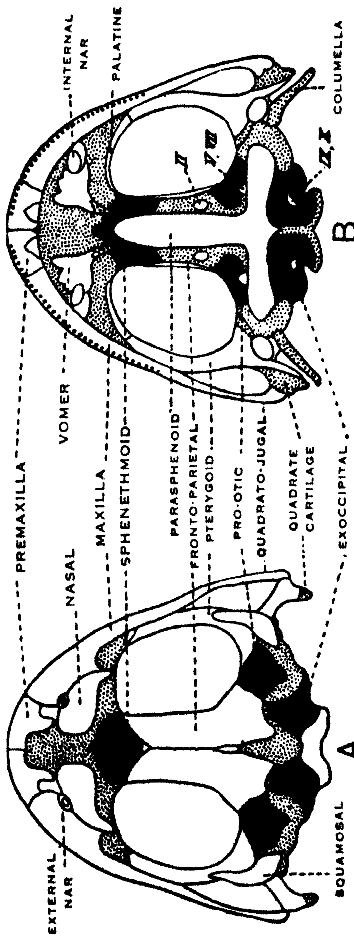


Fig. 130. Skull of Adult Frog.
A, Dorsal; B, Ventral view. Cartilage, dotted; Cartilage-bone, black; Membrane-bone, white. (After Reynolds.)

The Skull.—The skull consists of:—(1) the cranium or brain case, (2) the nasal or olfactory capsules, (3) the auditory or otic capsules, (4) the visceral arches.

(1) *The Cranium.*—From the cranium the nasal capsules project in front and the auditory capsules from the sides at the hinder end. The two large spaces at the sides of the cranium are the orbits. The hinder part of the cranium, called the occipital region, consists of a pair of cartilage bones, the **exoccipitals,**

one on each side of a large opening, the foramen magnum, through which the spinal cord passes to the brain. Each exoccipital bears an occipital condyle (Fig. 130). The middle part of the cranium, between the orbits, is called the sphenoidal region. It consists of a dagger-shaped bone, the **parasphenoid,** forming the floor, and two **frontoparietals** overlying the cartilaginous roof, which is pierced by three holes called fontanelles. The front part, ethmoidal region, consists of the **sphenethmoid,** which is a cartilage bone. This bone is like a tubular box and is divided across the narrowest part by a partition which closes the cranium in

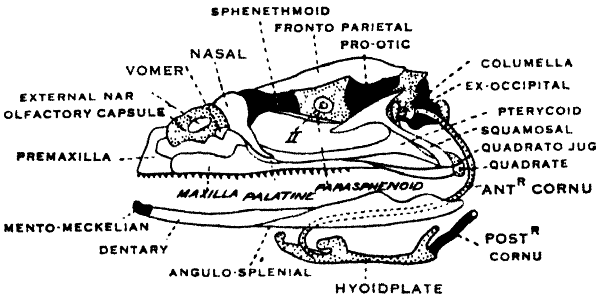


Fig. 131. Side View of Skull of Adult Frog. (After Howes.)

front. The front part of the sphenethmoid is divided into two lengthwise, and these two cavities enclose the olfactory lobes of the brain. The cranium is pierced by holes, or foramina, through which the ten pairs of cranial nerves pass out from the brain. Some of these are shown in Fig. 130, B, the numbers indicating the nerves passing through.

2. *The Nasal Capsules.*—The nasal capsules (or olfactory capsules) are enclosed largely by cartilage. The hind part is enclosed partly by the front part of the sphenethmoid. On the roof of each capsule is a membrane bone, the **nasal,** and on the floor another membrane bone, the **vomer** (Fig. 131). Each vomer has on it a patch of teeth which

project through the skin of the roof of the mouth. The two nasal capsules are divided from each other by a wall, the **mesethmoid**, and each has an opening above, to the nostril, and below, to the mouth.

3. *The Auditory Capsules.*—The auditory capsules, or otic capsules, are also largely surrounded by cartilage. The bones of the capsule comprise the **prootic**, which is a cartilage bone, and the **squamosal**, a membrane bone. In a side view of the skull (Fig. 131) the squamosal is seen to be T-shaped. The space enclosed by the auditory capsules is very irregular in shape and called the cartilaginous labyrinth. It contains the ear. At one place there is a gap in the cartilage, closed over only by a membrane, known as the **fenestra ovalis**, and from it a tiny rod of bone, the **columella** (Fig. 131), runs to the ear drum.

4. *The Visceral Arches.*—The visceral arches consist of the jaws and the plate of cartilage called the **hyoid**. Each jaw consists of two cartilaginous arches, one on each side. The arches of the upper jaw are called **palato-pterygo-quadrate**, and those of the lower jaw **mandibular**, or Meckel's cartilage.

The inner part of each palato-pterygo-quadrate arch is overlaid by two membrane bones, (1) **palatine**; (2) **pterygoid**, and (3) a strip of cartilage, the **quadrate**. The outer part of the arch is covered by three membrane bones: (1) **premaxilla**, (2) **maxilla**, both bearing a row of teeth, and (3) **quadrato-jugal**, which connects the maxilla with the quadrate cartilage.

The lower jaw articulates with the quadrate. The mandibular arch consists of **Meckel's cartilage.** In the front there is a tiny cartilage bone, the **mentomeckelian**; and the arch is almost enclosed by two membrane bones, the **angulosplenial** on the inner side and the **dentary** on the outer side.

The **hyoid** (Fig. 132) has two processes called **cornua** at

each end. The anterior cornua are long as they curve backward to be attached to the auditory capsules (Fig. 131). The posterior cornua are cartilage bones.

A tadpole's skull consists entirely of cartilage (Fig. 133), and a good deal of this remains in the adult frog's skull, but some of it becomes changed into bone, while most of it becomes overlaid to some extent by membrane bones.

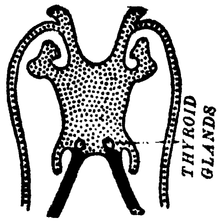


Fig. 132. Hyoid of Adult Frog.

The Pectoral Girdle.—The bony girdle to which the front limbs are attached is called the shoulder, or pectoral girdle (Fig. 134). It consists of two similar halves. The shoulder blade consists of a bone, the **scapula**, and the suprascapula which has a bony centre covered with cartilage. Attached to the scapula are two bones, the **coracoid** and the **clavicle.** The latter is the only membrane bone outside the skull. Between the coracoid and clavicle of the one half of the girdle and those of the other half is a strip of cartilage uniting the two halves of the girdle. From the anterior end of this cartilage arises a bone called the **omosternum** on to which is attached a cartilage, the **episternum.** From the posterior end projects another bone, the **mesosternum,** from which projects a cartilage, the **xiphisternum.** This strip, consisting of bones and cartilage, lies near the ventral surface of the animal. The shoulder blades are bent back to the dorsal surface and are attached by ligaments and muscles to the backbone.

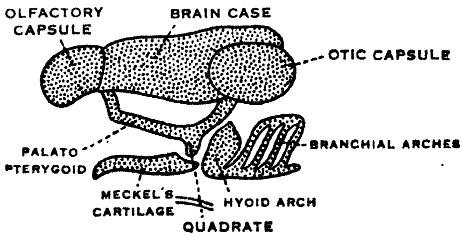


Fig. 133. Side View of Skull of Tadpole.

At the junction of the coracoid and scapula is a socket, the glenoid cavity, into which fits the upper arm bone. The upper arm contains one bone, the **humerus,** the head of which forms a ball to fit into the glenoid cavity. The opposite end of the humerus, the trochlea, is also swollen. On to the trochlea fits the bone of the forearm, forming the elbow joint. This bone is called the **radio-ulna,** because in many four-limbed animals there are two distinct bones, radius and ulna, and even in frog it

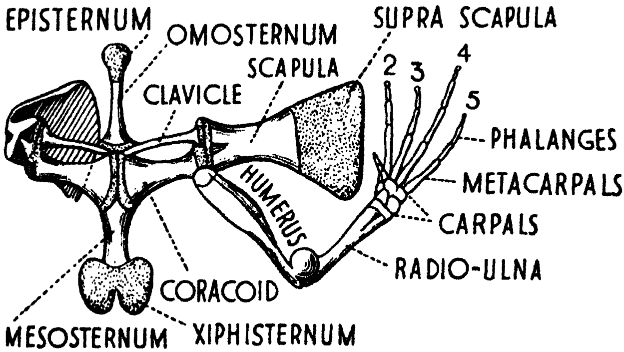


Fig. 134. FROG.
Shoulder-Girdle and Fore Limb. (After Howes.)

is imperfectly divided into two towards the hand. The wrist consists of six small bones, called **carpals,** arranged in two rows of three. The four fingers of the hand are complete, but the thumb is reduced. Each finger has a bone next the wrist called the **metacarpal.** The other finger bones are **phalanges,** and the first and second fingers have two, while the third and fourth have three. The thumb has only a metacarpal bone.

THE PELVIC GIRDLE.—The girdle supporting the hind limbs is called the hip, or pelvic girdle. It is made up of two halves, each consisting largely of a long hip bone, the **ilium,** which articulates at one end with the

transverse processes of the ninth vertebra. At the other end the two hip bones fuse together (Fig. 128), after passing backwards parallel with the urostyle. Beyond their union is a flattened bony mass. Each side of this (Fig. 135) consists of three distinguishable pieces:—two bones, the ilium and **ischium**, and the **pubis**, a triangular piece of cartilage, between them. Approximately in the middle of each side is a socket, the acetabulum, into which fits the leg bone.

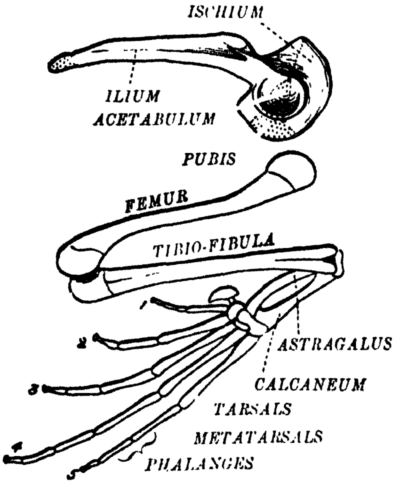


Fig. 135. FROG.
Pelvic Girdle and Hind Leg.

The upper part of the leg contains one bone, the thigh bone or **femur**. Its head is rounded to fit into the acetabulum and form the hip joint. The other end is widened to articulate with the bone in the shank, the **tibio-fibula**, so called because in many animals there are two bones, the tibia and the fibula. The bones in the ankle are called **tarsals**. There are four, placed in two rows. The two nearest the tibio-fibula are much longer than the other two and

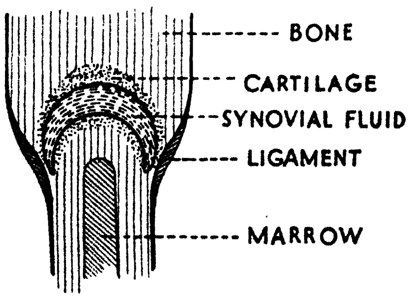


Fig. 136. DIAGRAM TO ILLUSTRATE STRUCTURE OF JOINT. (After Borradaile.)

are known as the astragalus and the calcaneum. The five toes are complete, each having a **metatarsal** and **phalanges.** The first two toes have two phalanges, the third three, the fourth four, and the fifth three. In addition to the five toes there is at the base of the first what appears to be a sixth one, consisting of a small metatarsal and sometimes one or two phalanges. This toe is visible in the skeleton but does not project and form a toe in the living animal.

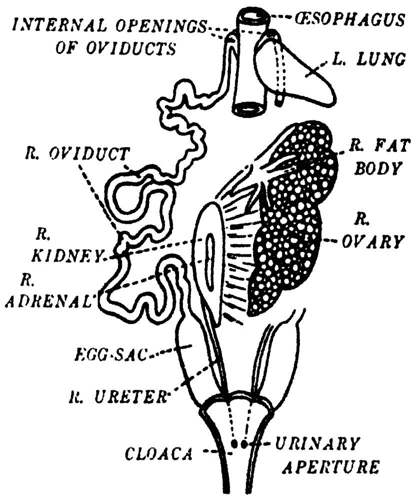


Fig. 137. URINOGENITAL ORGANS OF FEMALE FROG.
The left ovary, kidney, etc., and most of the left oviduct and the bladder are omitted. (After Howes, altered.)

MUSCLES.—The movements of the animal's body are due to **muscles** which act under the direction of the nervous system. Muscles, the movement of which can be controlled by the will, are called voluntary. These are attached to two different bones of the skeleton by means of tendons. Between the two bones is a joint, and under the action of the muscle one bone will move, while the other remains comparatively fixed. The attachment of the muscle to the more movable bone is called the insertion, and the other attachment the origin. When the muscle becomes wider and therefore shorter, that is contracts, one bone is drawn up closer to the other. Muscles always occur in pairs, so that when one has contracted and caused movement, the original position may be regained by the action of the other.

JOINTS.—In a perfect **joint** the end of one bone is rounded to fit inside a hollow on another bone. The socket is lined, and the ball covered, with cartilage Between the two bones is a bag containing synovial fluid. The ends of the two bones are held together by ligaments (Fig. 136). When the joint is perfect, free movement is possible. In an imperfect joint there is only a layer of cartilage between the ends of the two bones and movement is limited, *e.g.* between the bones of the frog's shoulder girdle.

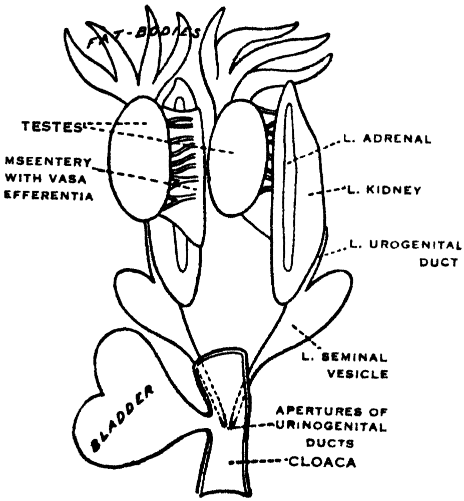


Fig. 138. URINOGENITAL ORGANS OF MALE FROG.
(After Howes, altered.)

THE REPRODUCTIVE SYSTEM.—The **reproductive organs** have been largely described in the course of the dissection. They are shown in Figs. 137 and 138. There is a pair of **ovaries,** each containing numerous ova, or eggs. The longest, or middle part, of the **oviducts** is thick-walled and secretes the jelly-like coating to the eggs. In the male, since the **testes** are connected with the kidneys by **vasa efferentia,** the kidneys are not only organs for the excretion of urine, but also transmit the sperms. This close connection between kidneys and reproductive organs has given rise to the term urino-genital organs. The duct of the kidney passes sperms as well

as urine and is therefore a **urino-genital duct.** The **seminal vesicle** on the duct acts as a storehouse for sperms. The fat bodies associated with ovaries and testes store fat for the period of hibernation. Mating takes place almost immediately the winter sleep is over, during late February and early March. The male embraces the female with the fore-limbs, the pad already noticed on the first finger of the male assisting in this, and as the eggs escape sperms are poured over them to fertilise them.

CHAPTER XI

THE RABBIT

1. EXTERNAL FEATURES

The dogfish spends its whole life, and the frog a good deal of time, in water, and the absence of a neck gives the body a better shape for swimming. The rabbit is entirely a land animal. It has a distinct neck separating the **head** from the remainder of the body, which is called the trunk (Fig. 139). The trunk is divided into a front or anterior part, the **thorax,** and a hind or posterior part, the **abdomen.** A noticeable feature is the short upturned tail which is white on the underside.

Like the frog, the rabbit has four **limbs,** a pair of front legs and a pair of back legs. The skeletons of the limbs in the frog and rabbit are very similar, since they are built on the same general plan. This type of limb is called **penta-dactyle,** but there are not always five digits: in the rabbit the front legs have five and the back legs only four. The digits each end in a horny claw. Instead of having pads on the soles of the feet, such as are present in cats or dogs, the rabbit has a thick coating of hair, which gives a firm grip on hard rock or slippery snow. A more obvious feature than this is the great length of the hind legs compared with that of the fore legs. When the

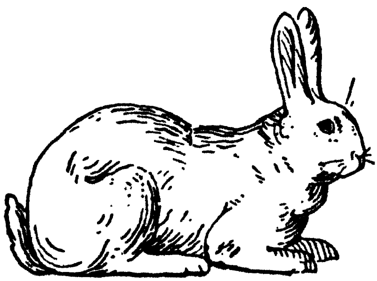


Fig. 139. RABBIT.

animal moves it pushes off, as it were, from its long back legs, and progresses by jumps.

The wild rabbits dig out extensive tunnels or burrows, 6 in. to 1 ft. wide, in the soil, and this is done largely with the front legs, while the back legs are used to kick back the loosened earth.

The head has remarkably long **external ears,** which feature was entirely absent in frog and dogfish. If laid forward over the face they nearly touch the tip of the nose. The large **eyes** are placed at the sides of the head. They have upper and lower **lids** like our own, and in addition a third eyelid, in the form of a white membrane, which closes completely over the eye from the corner. The **nose** has two nostrils which open internally into the pharynx instead of into the front of the mouth as in frog. There is also a pair of **lips,** of which the upper one is deeply cleft in the centre. There are long whiskers on the sides of the nose, and shorter round the eyes. These are very sensitive to touch.

There are two openings on the ventral surface of the body just behind the tail. One is the **anus,** the end of the alimentary canal, and in front of this there is the **urinogenital opening.** In the male the latter is on the end of a penis, but in the female within a slit-like vulva. Along the ventral surface of the female are the openings of the milk or mammary glands. As the anus and urinogenital openings are separate there is no cloaca as found in frog.

The fur in a wild rabbit is tawny grey except for the white underside of the tail, but he has many relatives with fur of different hues and often longer than his own. These varieties of the wild rabbit man has produced by breeding. There are actually three different sets of hairs in the fur; some short, dense, soft, and woolly; some long and stronger, which give the colour; and others yet longer, but fewer in number. All these hairs grow from the rabbit's skin.

The rabbit belongs to the highest class of backboned animals, namely the **mammals.** This class is characterised by possessing hair. The mammalian class is divided into orders, and the rabbit belongs to the gnawing animals or **rodents,** on account of the fact that they are continually gnawing hard substances, such as wood. By doing this they sharpen their front teeth.

The wild rabbits live together in large companies, and unless the ground is too hard or too wet to dig, they make a complicated system of burrows. The passages end in rooms used for sleep and also as nurseries. The burrows obviously provide a means of escape from danger. As they live together in this way, when the whole company is feeding, one is able to give the rest warning of approaching danger.

The female rabbit, or **doe,** possesses a longer and better shaped head than the male, or **buck.** The doe has about four families or **litters** per year, and each contains five to eight young ones. This should give you an idea of the rapidity with which their numbers increase. The average life of a rabbit, barring accidents, such as being trapped or shot by an irate farmer, or attacked by one of its animal foes, is seven or eight years.

Usually the rabbit is silent except for low noises made when it is angry or surprised, but if it is in danger from its mortal enemy the *stoat,* it screams loudly.

The rabbit is a vegetarian. It feeds largely on grass and the young shoots of furze, but if it is in the neighbourhood of farm lands it causes the farmer much annoyance by devouring lettuce, cabbages, carrots, turnips, and other root crops. A rabbit requires no water to drink, as his vegetable diet supplies his body with a sufficiency. The only animal food he ever takes is an occasional snail.

The entrance to the **alimentary canal** is the **mouth,** leading to the buccal cavity, the roof of which consists of a **palate,** which separates it from the nasal chamber above

(Fig. 140). The front part of the palate is hard as it is strengthened by parts of the premaxilla, maxilla and palatine bones of the skull. The hind part is entirely fleshy and is called the soft palate. The tongue is attached along the floor of the mouth and is free at the tip. The **teeth** are the first organs to act in digestion, since they break the food up into smaller portions which may be more readily attacked in the buccal cavity as well as in other parts of the canal.

The rabbit has a set of small **milk teeth** followed by larger permanent teeth of which there are more, and which are of a more suitable size to fit in the larger gums of the adult. In order that they may work efficiently there are two kinds of teeth, thin ones with sharp cutting edges, known as **incisors**, and others with broad, ridged tops. The latter grind the food between them, just as corn may be ground into flour between millstones. These are known as **premolars** if they were preceded by milk teeth and **molars** if not. A rabbit has six incisors, four in the upper and two in the lower jaw; ten premolars, three on each side of each upper and two on each side of each lower jaw, and twelve molars, three on each side of each jaw.

The number of teeth and their arrangement are indicated by a dental formula in which the kind of tooth present in half the upper jaw is put over the number of corresponding teeth in half the lower jaw, and the teeth on the left-hand side of the formula are those in the front of the mouth. As other mammals possess canine teeth these are indicated in the formula as being absent in the rabbit, so that it reads as follows: i. $\frac{2}{1}$ c. $\frac{0}{0}$ pm. $\frac{3}{2}$ m. $\frac{3}{3} = 28$. There is a very large gap between the incisors and the premolars. This, and the general appearance and arrangement of the teeth, can be seen in the views of the skull (see Figs. 171 and 172). It will be seen that the rabbit has in all twenty-eight permanent teeth, whereas the maximum for mammals is forty-four.

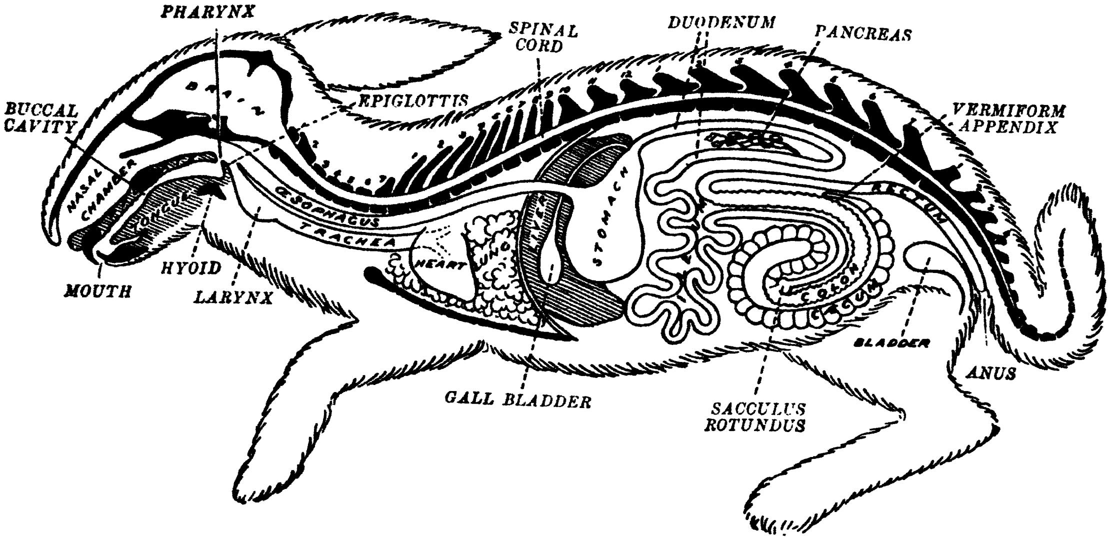


Fig. 140. General Anatomy of Rabbit.

The cervical, thoracic, lumbar, and sacral vertebrae are numbered. The double line between "Lung" and "Liver" is the Diaphragm. The abdominal part of the alimentary canal is shown diagrammatically. (Outline and bones after Marshall and Hurst.)

2. DISSECTION

Young rabbits are best for dissection and must be skinned. The skin comes off more easily while the rabbit is still warm. It can be killed by putting it into an air-tight box containing chloroform. To remove the skin make a longitudinal slit on the ventral surface, then with a scalpel and the hands loosen the skin from the body wall, pull out the hind limbs, cut off the external ears, cut and pull the skin from the neck and head. The skin can be cut off from the paws and from the nose if any remains there.

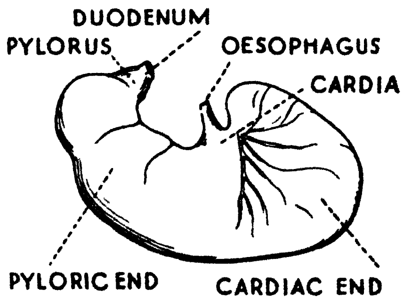


Fig. 142. STOMACH OF RABBIT.

Lay the animal on its back on a board and fasten it down by means of large pins or awls through the limbs. Make a median cut through the body wall from the hind end of the breast bone to the pelvic girdle. From the anterior end of this cut, cut outwards on each side just below the ribs for about two inches. Turn the flaps of the body wall back on each side and pin them down. The most anterior organ in the abdomen is the liver, and immediately behind it lies the **stomach** (Fig. 141). The mouth communicates with the stomach by means of the oesophagus, which is only visible in a dissection of the thorax. If the liver is turned forwards the stomach can be seen properly. It lies across the body and is wider on the animal's left side. This is called the cardiac end and the narrower end is the pyloric end. Its anterior border curves in and here the **oesophagus** enters (Fig. 142).

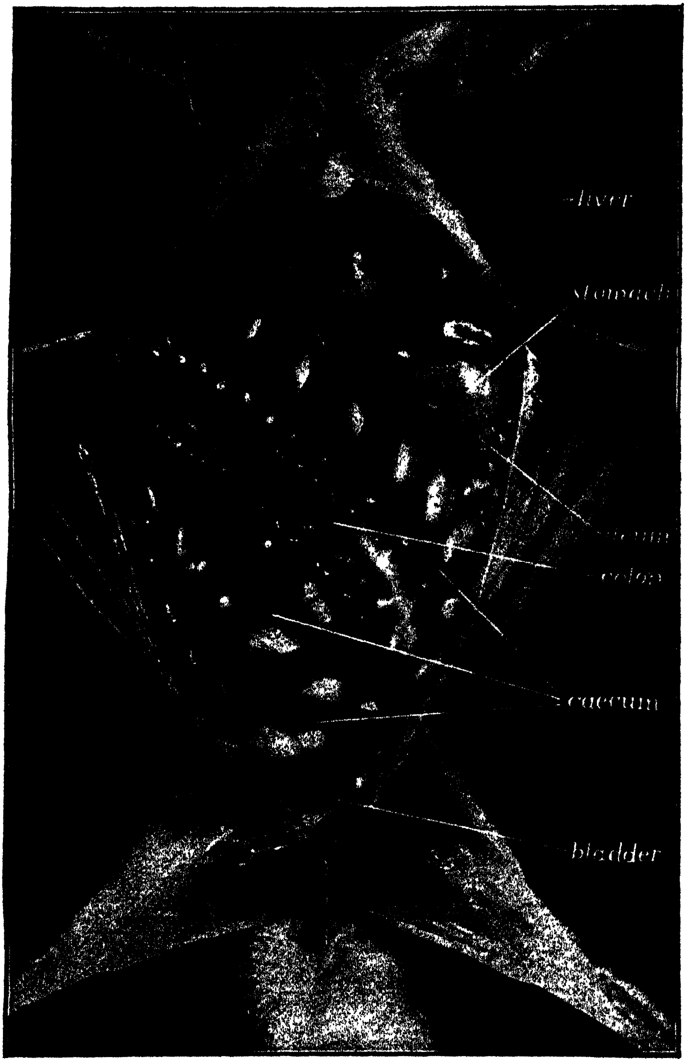


Fig. 143. Rabbit.

The Abdominal Viscera exposed. (From *The Dissection of the Rabbit* by R. H. Whitehouse, D.Sc., and A. J. Grove, M.A., D.Sc.)

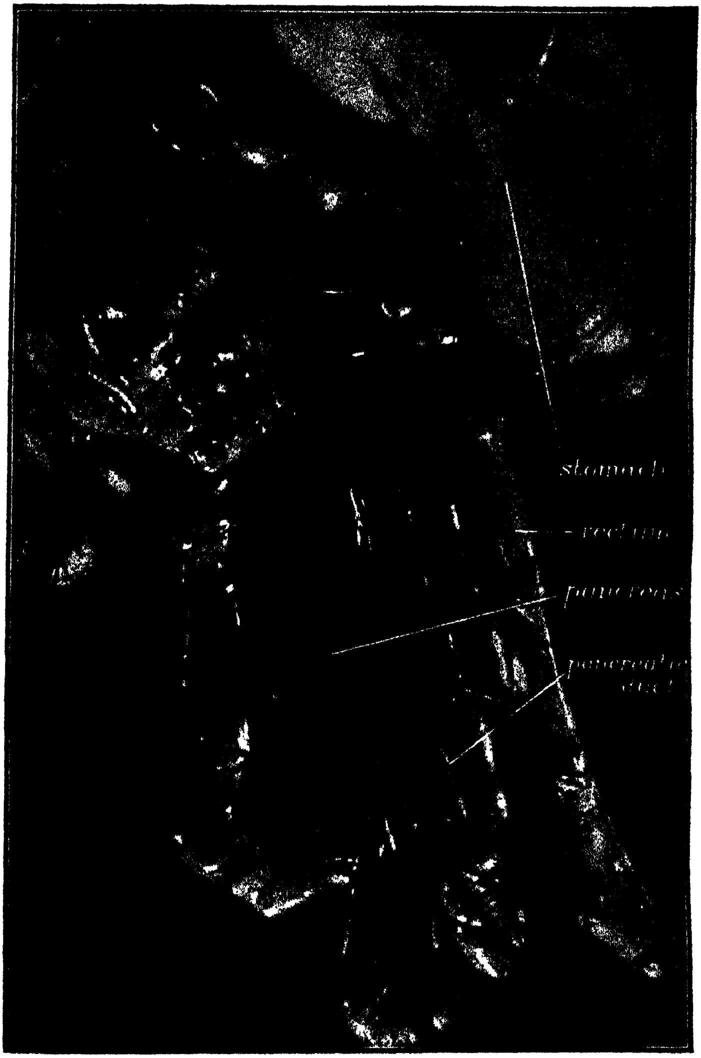


Fig. 144. RABBIT.

The Duodenal Loop and Pancreas. (From *The Dissection of the Rabbit* by R. H. Whitehouse, D.Sc., and A. J. Grove, M.A., D.Sc.)

The intestine leads out of the pyloric end of the stomach. The first part is called the **duodenum.** It is a **U**-shaped loop lying along the right side of the abdominal cavity and reaching almost to the posterior end of it. Turn the duodenum over to the left side and spread it out. In the mesentery within the loop is a much branched gland, the **pancreas** (Figs. 140 and 141). A duct runs through the gland and opens into the duodenum. The rest of the **small intestine,** called the ileum, is seven to eight feet long and therefore must be coiled in order to fit into a small space. It can be unravelled by cutting the mesentery where necessary. Blood vessels should be cut close to the gut so that loss of blood will be slight. The small intestine ends in a rounded swollen portion, the sacculus rotundus. The alimentary canal continues as the **large intestine** consisting of (1) the wide **colon,** about one and a half feet long; (2) the **rectum,** which is narrower than the colon, about two and a half feet long, and has a beaded appearance due to the pellets of solid waste products that it contains. It ends at the anus. Where the small and large intestine join there is the **caecum.** This is a wide tube, the outer surface of which is spirally constricted. It ends blindly in the vermiform **appendix.**

The internal structure of the alimentary canal can also be seen to some extent with the naked eye. Slit open the stomach along the posterior edge, wash out the contents and note in the wall: (1) an outer layer; (2) a middle muscular layer, thicker at the pyloric end; (3) an inner layer of mucous membrane raised into folds running the length of the stomach. The exit at the pyloric end of the stomach is narrowed by a rim of muscle, the sphincter, the action of which allows only a small quantity of food to enter the intestine from the stomach at a time. This control is necessary because the contents of the stomach are acid and those of the intestine need to be alkaline.

Cut out a small piece from the wall of the small intestine. Its inner surface is velvety owing to numerous finger-like projections, the villi, see Chapter XII.

Cut across the ileum and the colon about an inch from the caecum, thus removing the latter. Slit open the caecum and notice the numerous papillae on the inner surface. Cut across the appendix, which has a very thick wall, while the caecum has a thin one. Slit open the colon and the rectum. The former has papillae on the inner surface, but in the latter it is a smooth mucous membrane.

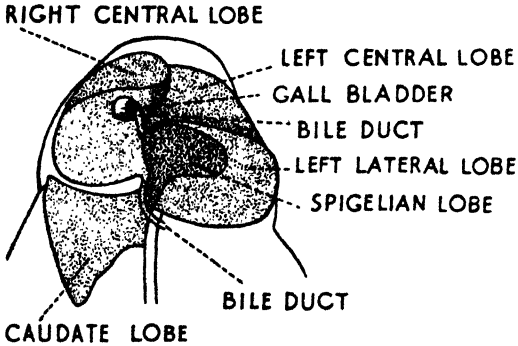


Fig. 145. LIVER OF RABBIT.

The process of digestion in the various parts of the alimentary canal is described in Chapter XXIV. The functions of caecum and appendix are doubtful.

The **liver** consists of five lobes (Fig. 145). Its anterior surface is convex and fits against the **diaphragm**, a curved shelf of muscle which completely separates thorax and abdomen; it is attached to the diaphragm by a fold of the peritoneum, called the falciform ligament. The concave, posterior surface of the liver fits against the stomach. In a groove on the posterior surface of the right central lobe of the liver lies the gall bladder. From this a duct enters the duodenum just below its junction with the stomach.

The examination of the alimentary canal having been completed, the whole can be removed by cutting across the oesophagus and the rectum. Fig. 146, C, shows the muscular body wall lined by a membrane, the peritoneum, and the organs in the body cavity. The alimentary canal hangs in the mesentery, which is a fold from the peritoneum.

To dissect the **thorax** it is necessary to remove the breast bone. The sides of the thorax in this animal are bounded by twelve or thirteen rib bones, missing in the frog. Cut across the thorax just in front of the diaphragm and

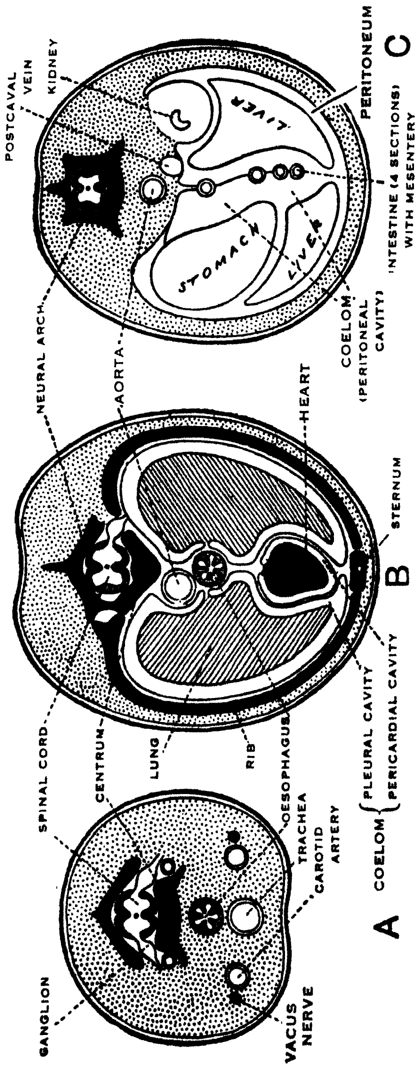


Fig. 146. Rabbit.
Transverse Sections: A, Across neck; B, Across thorax; C, Across abdomen (slightly diagrammatic).

then through all the ribs except the first along each side, so that a triangular piece of the wall of the thorax can be removed. Anteriorly there is a soft gland, the **thymus,** which is often very large (Fig. 147). The **heart** is in the middle of the thorax and is surrounded by a thin membrane, the pericardium. The pointed end is directed backwards and slightly to the left. The **lungs,** which are like pink sponges, fill most of the thorax, but they collapse

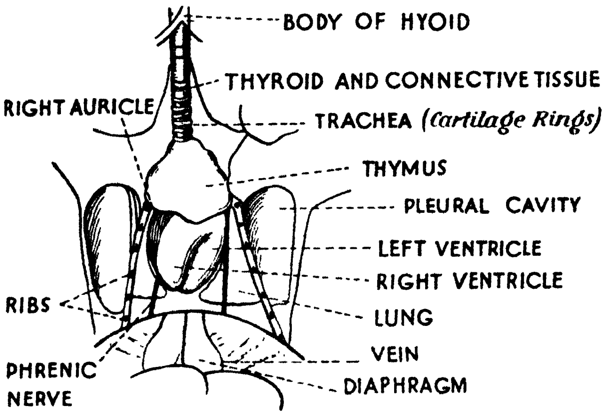


Fig. 147. RABBIT.
Thorax and Neck.

when it is opened. The left lung has only two lobes and the right one four (Fig. 148).

The thorax is lined by a membrane that glistens and is called the **pleura.** Each pleura is folded over the lung so that a pleural cavity is formed around each lung, just as a pericardial cavity is formed around the heart (Fig. 146, B). Leading from the thorax into the neck there is a tube called the **trachea,** or wind-pipe. This will be seen more clearly if the thymus is removed. It is strengthened with rings of cartilage, passes dorsal to the heart, at about the level of the middle of which it divides into two **bronchi,**

one for each lung. Dorsal to the trachea is the oesophagus, which can be seen by raising the left lung. It is distinguished from the trachea by having no rings of cartilage.

The **blood vascular system** consists, as in frog, of heart, veins, arteries, and capillaries. Expose the **heart** by removing the thymus and the **pericardium**, and clean the roots of the large blood vessels, which arise from or leave the broad end, or base, of the heart. The pointed end of the heart consists of two **ventricles**, as shown by a groove on the outside. The base consists of two **auricles**, but as these are dorsal to the ventricles only a small part of them is visible. The large **veins** open into the two auricles of the heart. Three return blood from the whole of the body except the lungs, and these open into the right auricle. The **right anterior vena cava** returns blood from the right side of the head, neck, and thorax and from the right fore-limb, and **left anterior vena cava** from the corresponding parts of the left side of the body. The **posterior vena cava** returns blood from all parts of the body posterior to the diaphragm, entering the thorax through an opening in the diaphragm. The right and left anterior venae cavae run along the inner side of the right and left lung respectively. The anterior and posterior venae cavae correspond with the superior and inferior venae cavae in man. The two **pulmonary veins** from the lungs open into the left auricle. It is easier to follow the veins from the larger to the smaller, that is backwards against the flow of the blood. As explained for frog, veins are darker in colour and nearer the surface than arteries.

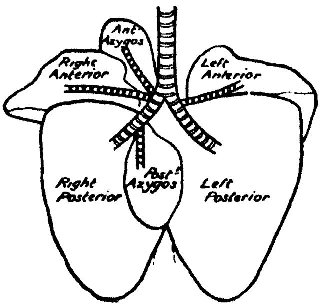


Fig. 148. LUNGS OF RABBIT.

that the first pair of ribs are attached at about the middle of the manubrium and the others between the segments.

THE SKULL.—The skull, as in the frog, consists of:—

(1) cranium;
(2) olfactory capsules;
(3) auditory capsules;
(4) visceral skeleton.

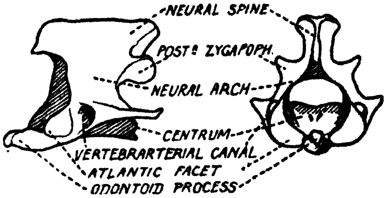


Fig. 167. RABBIT.
Axis. Side and front views.

Most of the bones in it are closely applied to one another by jagged sutures. As in the frog, there are many tiny holes, or foramina, through which cranial nerves pass out, and one large hole, the foramen magnum, at the base, through which the spinal cord passes.

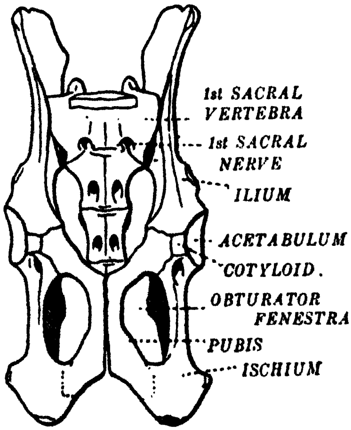


Fig. 168. RABBIT.
Pelvic Girdle and Sacral Vertebrae.

1. *The Cranium.*—In the cranium the bones are arranged in rings. The hindermost, or **occipital ring**, consists of four bones surrounding the foramen magnum. The ventral one is the **basi-occipital**, the two laterals are **ex-occipitals**, and the dorsal one is the **supra-occipital** (Fig. 171). Two large knobs, **occipital condyles**, which fit into the atlas are mainly on the ex-occipitals, but partly on the basi-occipital. Each ex-occipital has a downwardly-directed **par-occipital process** (Fig. 172).

The **parietal ring** consists of:—(1) the **basi-sphenoid**, which is triangular and is connected with the basi-occipital by cartilage; (2) the **alisphenoids** at the sides; (3) the **parietals,** a pair forming the roof (Fig. 173) which are membrane bones; (4) the **interparietal,** which is a tiny membrane bone between the parietals and the supra-occipital.

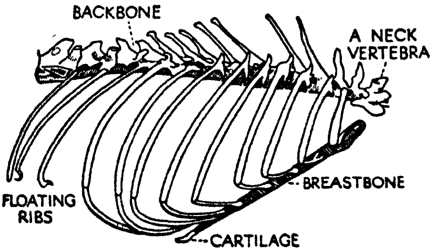


Fig. 169. RABBIT. Ribs.

The **frontal ring** is composed of:—(1) the **presphenoid,** a very tiny bone in front of the basi-sphenoid to which it is connected by cartilage; (2) **orbito-sphenoids** at the sides, which surround the optic foramen and are fused with the presphenoid; (3) **frontals,** a pair of membrane bones, which complete the sides and form the roof.

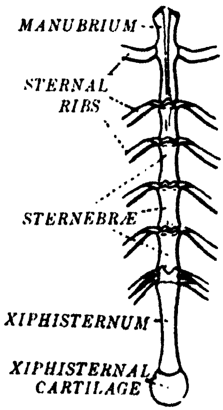


Fig. 170. RABBIT. Sternum.

2. *The Olfactory Capsules.*—The olfactory, or nasal, capsules consist of:—(1) **nasals,** a pair of long membrane bones forming the roof of the nasal cavities; (2) the **mesethmoid,** which is a cartilage bone in front of the presphenoid and extends down to separate the nasal cavities; (3) **vomers,** a pair of membrane bones on the ventral surface, which enclose the lower edge of the mesethmoid and are extended behind to form a horizontal partition separating the olfactory chambers from a narial passage leading to the throat;

(4) **turbinals,** three pairs of thin, much-folded bones, which project from the walls into the nasal cavities, thereby increasing their inner surface.

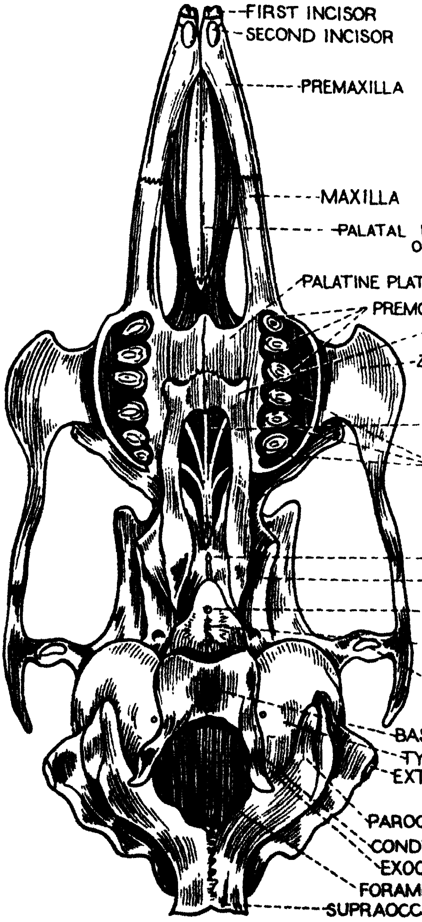


Fig. 171. Rabbit.
Skull. Ventral view.

3. *The Auditory Capsules.*—The auditory capsules each consist of:—(1) a **periotic,** which fits loosely between the exoccipital and the squamosal bone of the upper jaw and has a dense, inner, petrous portion enclosing the actual organ of hearing and a porous, outer, mastoid portion; (2) a **tympanic,** which is flask-shaped. The body of the flask, called the bulla, encloses the tympanic cavity (Chapter XIII.), and the neck, called the external auditory meatus, leads from the ear drum to the ear opening. Between the bulla and the meatus is a bony ring across which the ear drum was stretched. If the tympanic bone is removed two holes are seen in the periotic. The anterior one is the fenestra ovalis and the other the fenestra rotunda. Between the former and the ear drum, in life, stretches a chain of three little bones (Chapter XIII.) which really belong to the visceral skeleton.

4. *The Visceral Skeleton.*—The visceral skeleton consists of the mandibular arch, which by division forms the upper and lower jaw. All the bones composing it are membrane bones. The bones of the **upper jaw,** some of which help to form the floor and sides of cranium and olfactory capsules, are as follows:—(1) **pterygoids,** a pair of narrow, vertical bones attached to the base of the skull at the junction of the basi-sphenoids with the alisphenoids; (2) **palatines,** another pair of almost vertical plates attached to the presphenoid above, and the pterygoids and alisphenoids behind; (3) **maxillae,** a pair of large bones prolonged outwards and backwards into a zygomatic process and bearing the upper grinding teeth; (4) **premaxillae,** which articulate with the anterior part of the maxillae and with one another and bear the incisor teeth; (5) the **jugals,** which are fused with the zygomatic processes of the maxillae in front, and zygomatic processes from a bone of the lower jaw behind; thus completing the **zygomatic arch** which bounds the orbits.

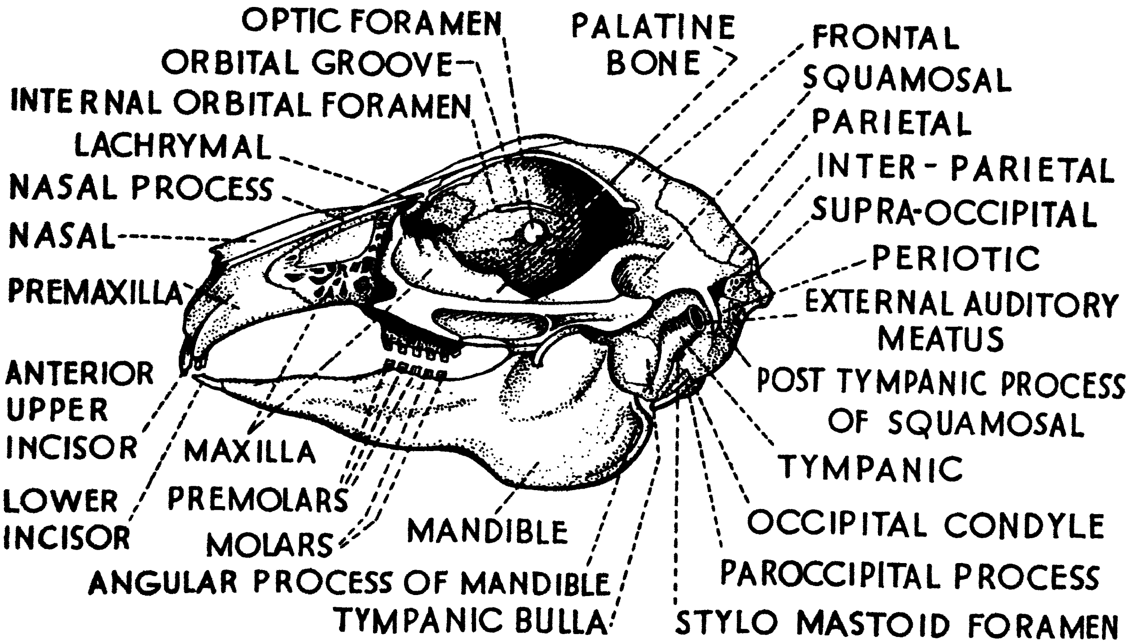


Fig. 172. Side View of Skull of Rabbit.

The **lower jaw** consists of:—(1) **squamosals,** a pair which are curved, complete the side walls of the cranium and the zygomatic arches by bearing the zygomatic processes, on the under surface of which is a facet for the articulation of the lower jaw; (2) **mandibles,** articulating

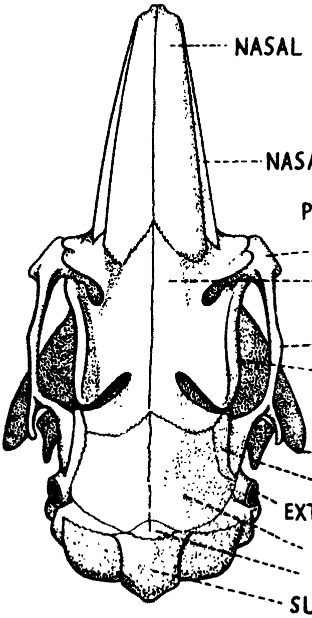


Fig. 173. Rabbit.
Dorsal view of Skull.

with the squamosals and each bearing an incisor tooth in front and the lower grinding teeth further back.

The **hyoid** bone, to which the tongue muscles are attached, is also part of the visceral skeleton. It has posterior and anterior cornua, the former being larger. The anterior cornua are connected by a small bone with the periotic part of the skull.

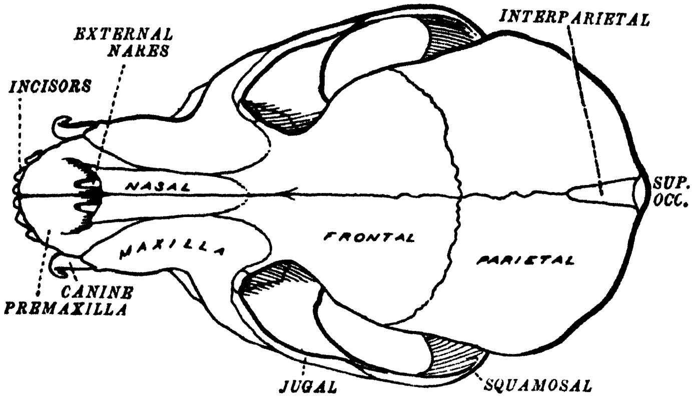


Fig. 174. Dog.
Skull. Dorsal view.

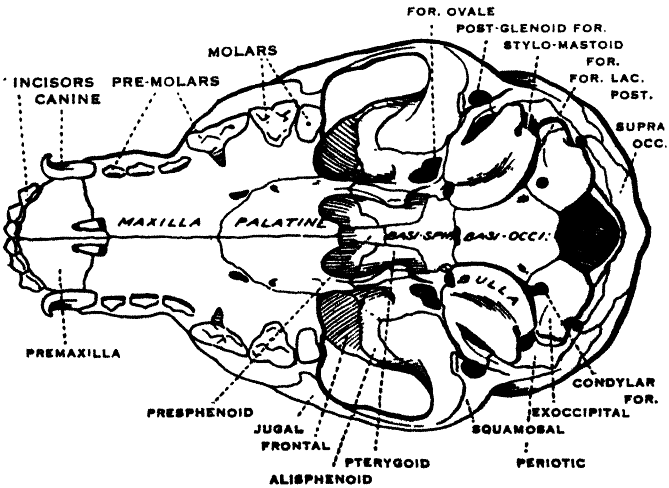


Fig. 175. Dog.
Skull. Ventral view.

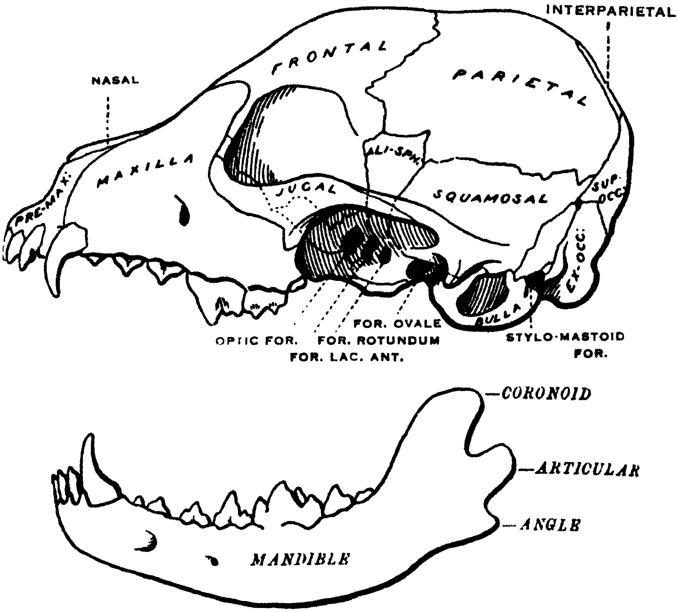


Fig. 176. Dog.
Skull. Side view.

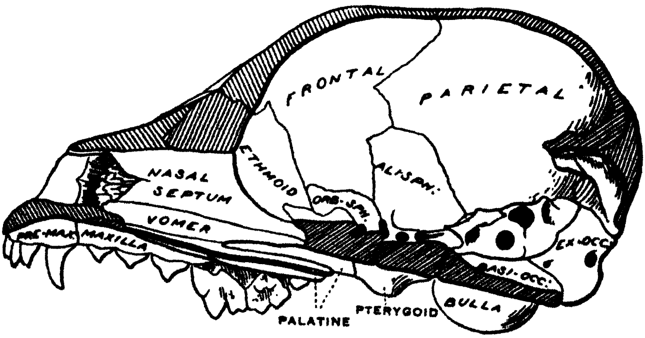


Fig. 177. Dog.
Skull. Median (sagittal) section.

In the dogfish the whole skull is cartilaginous and the lower jaw suspended by the hyomandibular cartilage.

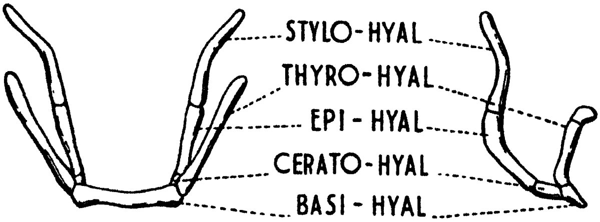


Fig. 178. Dog.
Hyoid. Posterior and side views.

The skulls of tadpoles and embryo rabbits are also cartilaginous, but during development some of the cartilage gradually becomes bony, and in addition new membrane bones appear. In the frog the lower jaw is suspended by the quadrate and in the rabbit by the squamosal, a membrane bone. The hyoid and its cornua in frog and rabbit represent the hyoid arch in dogfish.

A dog's skull is larger to study than that of rabbit. The most obvious difference between the two skulls is the number of the teeth. The dog's skull is shown in Figs. 174-177, and the dental formula can be seen to be: i. $\frac{3}{3}$ c. $\frac{1}{1}$ pm. $\frac{4}{4}$ m. $\frac{2}{3}=42$. The hyoid apparatus in the dog is shown in Fig. 178. The basi-hyal is the hyoid bone and the other bones form the cornua.

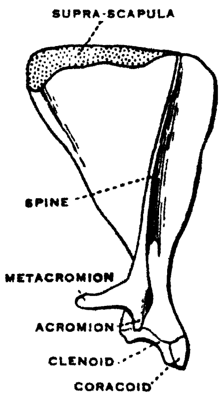


Fig. 179. Rabbit.
Scapula of a young animal. (The shape is slightly different in the adult.)

As in the frog, in addition to the axial skeleton, there is an appendicular one. The ribs and breastbone already

described are part of the latter and the limb girdles and limbs constitute the remaining part.

THE PECTORAL GIRDLE.—The pectoral, or shoulder, girdle consists of a large, flat, triangular **scapula,** or shoulder blade, on each side. The apex of the triangle is forwards and downwards, and on the outer surface of the bone is a ridge which ends near the apex in two processes, the acromion and metacromion (Fig. 179). At the apex of the triangle is a socket, the glenoid cavity, into which fits the fore limb. Close to the glenoid cavity is a projection which is a separate bone in the embryo and represents the **coracoid** bone in the frog. In a ligament, which runs from the scapula to the sternum, lies a small rod-like bone, the collar-bone, or **clavicle.** The bones of the **fore limb** closely resemble those of frog. At the elbow end of the humerus, just above the trochlea and in the posterior surface, is a dent called the olecranon fossa. Below the head is a deltoid ridge for the attachment of the deltoid muscle. The radius and ulna are distinct, but cannot move on one another. The radius is in front of the ulna, so that the palm is turned downwards, that is in the prone position. There are nine carpals, three in a row nearest the shoulder, one central one, and five in the distal row (Fig. 180). In the row

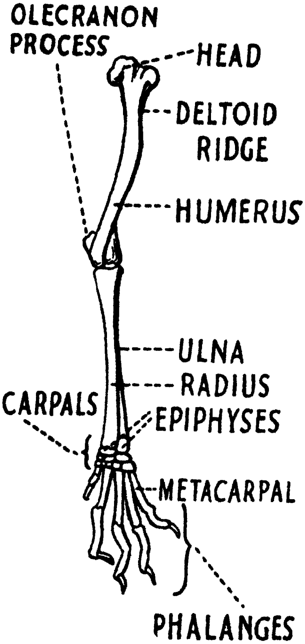


Fig. 180. RABBIT. Fore Limb. Front view.

of five, two are fused with one another. Each digit has a metacarpal, and the thumb has only two phalanges, but the others have three. The ulna has a projection, olecranon process, to which the extensor muscles which straighten out the limb are attached. It fits into the olecranon fossa when the limb is straight.

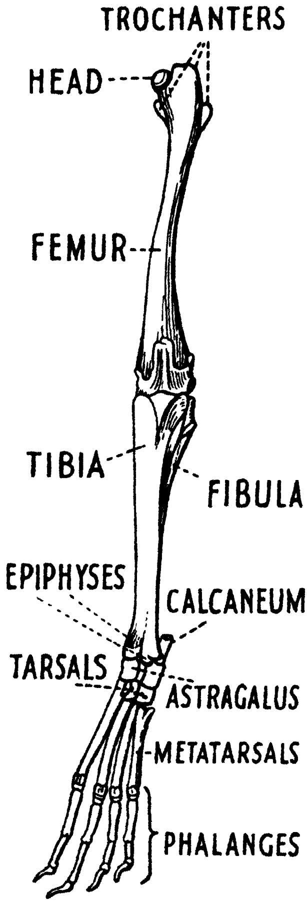


Fig. 181. RABBIT. Hind Limb. Front view.

THE PELVIC GIRDLE.—The pelvic, or hip, girdle consists of two halves and with the sacrum of the backbone forms a complete ring, called the pelvis (Fig. 168). Each half consists of:—(1) an **ilium,** which articulates with the sacrum; (2) an **ischium,** which is dorsal; (3) a **pubis,** which is ventral. The pubis on one side almost meets that on the other, there being just a narrow strip of cartilage, **symphysis,** between them. The large space between pubis and ischium is closed with a membrane and therefore called a fenestra. The hollow into which the femur fits is called the acetabulum and bordering it on one side is a little bone called the **cotyloid.**

The **hind limb** has a femur, a tibia and a fibula, but the the two last are fused for half the length. There are six tarsals in the ankle. Two lie side by side, one of which

projects to form the heel and is called the calcaneum (Fig. 181). There is a central bone and three in a row. There are only four digits, not five as in the fore limb, and each has a metatarsal and three phalanges. In life a bone called the knee-cap, or patella, in the tendon of the muscles, covers the knee joint and is connected by ligaments with the tibia.

Many of the most familiar animals, including ourselves, are mammals, and their skeletons are all very similar. In hoofed mammals the number of digits in the feet is often reduced. The horse has only one and the heel is so far off the ground that it runs on the tip of this one. This makes the horse very fleet of foot.

CHAPTER XII

ANIMAL AND PLANT TISSUES

1. INTRODUCTORY

The unit of both animal and plant life is a cell, which must consist of protoplasm with a nucleus. As animal bodies become more complex the cells become varied in shape, size, arrangement and contents according to their functions. A group of cells which are similar in structure and function is known as a tissue. In animals the cells forming a tissue are commonly separated from one another by a semi-fluid, known as **ground substance**, across which they are connected by protoplasmic threads. This substance is laid down by the cells themselves and also varies in the different tissues. For convenience, the tissues are classed as:—**epithelial**, **connective**, **muscular** and **nervous.**

2. EPITHELIAL TISSUES

These cover the whole body externally, line the digestive, respiratory and urinogenital tracts, secretory glands and ducts, the ventricles of the brain and the central canal, and the cavities of the internal ear, cover the tendons and nerves, and form the innermost lining of blood vessels and lymphatics. These tissues have very little ground substance. When only one layer of cells is present they are said to be simple, if more than one layer thick they are said to be compound.

SIMPLE EPITHELIA.—Simple Epithelia are further divided according to the form of the cells into:—

(*a*) *Pavement Epithelium.*—This forms thin membrane and consists of very thin cells, with wavy or diamond-shaped outlines, which form a mosaic, tessellated, pavement

structure (Fig. 182). These are easily seen if treated with silver nitrate, which forms a compound with the

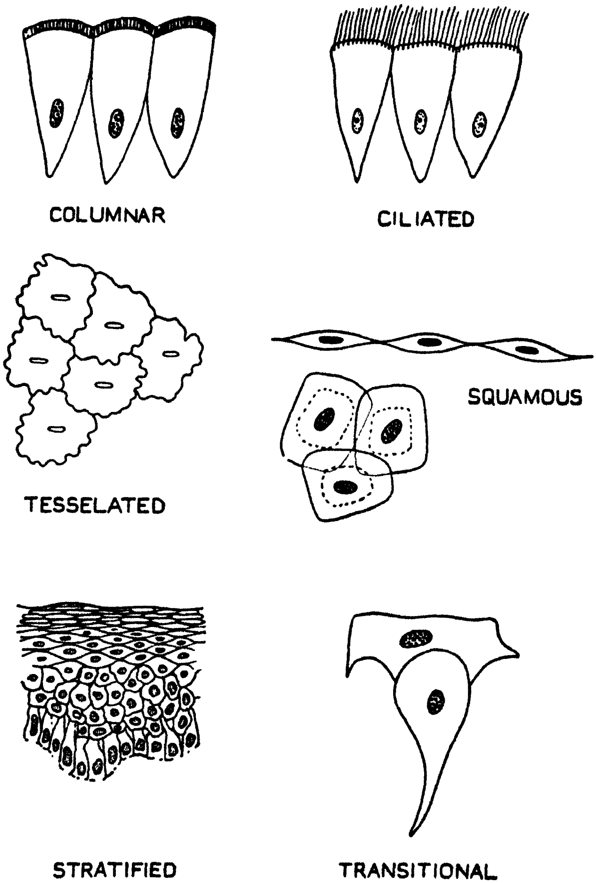


Fig. 182. THE VARIOUS KINDS OF EPITHELIA.

ground substance between the cells and is reduced to metallic silver in sunlight. This tissue lines blood and lymphatic vessels, covers tendons and nerves, and so on.

It forms a distensible elastic membrane, which offers a small amount of resistance to diffusion.

(*b*) *Cubical Epithelium.*—This lines the ducts and alveoli, or small spaces, of glands. The cells are approximately cubical, and very regular in size and appearance.

(*c*) *Columnar Epithelium.*—In these tissues the cells are taller than they are broad (Fig. 182). They are either cells with oval nuclei, well-marked upper borders, and granular cytoplasm, or they are goblet cells, which secrete mucilage (Fig. 183). The former are found at the openings of the glands at the cardiac end of the stomach, in the pyloric glands, covering the surface of the villi of the small intestine. The goblet cells occur in great abundance in the large intestine. Their appearance is due to the formation just above the nucleus of mucin; this absorbs water, the cell swells in this region and pushes the nucleus downwards. The cell bursts and discharges its contents, then is rejuvenated.

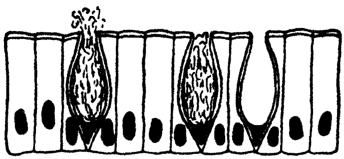


Fig. 183. COLUMNAR EPITHELIUM WITH THREE GOBLET CELLS.

(*d*) *Ciliated Epithelium.*—Here the cells are columnar in form, with the free edge covered with cilia (Fig. 182). These occur in the respiratory passages, ventricles of the brain, canal of the spinal cord, mucous membrane of the uterus and vasa efferentia. They sweep clean the surfaces on which they are found, and help the passage of material over them.

(*e*) *Glandular or Secretory Epithelia.*—Invaginations of the epithelia occur, so that epithelial cells surround a central lumen, or hollow space. The cells are somewhat wedge-shaped, and secrete material into the central space (Fig. 184). The number of cells varies considerably. In

liver, two or three cells surround the lumen, in the glands at the pyloric end of the stomach there may be twenty. The lumen may be large or small according to the condition of the gland.

COMPOUND EPITHELIA.—Compound Epithelia are divided into:—

(*a*) *Transitional Epithelia.* The bladder and ureters have three or four layers of cells. The cells of the inner layer are small, with well defined nuclei and capable of dividing. The superficial cells enlarge and become pear-shaped or scale-like (Fig. 182).

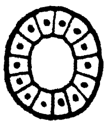


Fig. 184. TRANSVERSE SECTION OF SIMPLE TUBULAR GLAND.

(*b*) *Stratified Epithelium.*—These have a much more protective function: they line the mouth, pharynx, and oesophagus, and also cover the outer surface of the body, the last being much thicker and stronger. In both cases there are many layers or strata of cells (Fig. 182). The innermost are spherical or columnar and divide actively by mitosis. The outer layers are more flattened and scale-like. The formation of new cells by the inner layers causes the outer cells to be gradually pushed further away from the growing region and gradually changed in shape. The cells of the inner layer are not so closely applied to one another, and a looser tissue with intercellular spaces results. In the outer skin, the outermost layers become more and more horny and flattened, and are sometimes called squamous epithelium. As the cells pass towards the surface their contents first become granular owing to a deposit of eleidin; later the cell protein consists of an increasing quantity of cystin, which makes them horny.

3. CONNECTIVE TISSUES

The functions of these tissues is to bind different portions of the body together, to supply support, toughness, and

some elasticity. They are distinguishable by their contents and by the nature of the ground substance in which they lie. These tissues are divided into **areolar, fibrous (lymphoid),** and **elastic (adipose) tissues, cartilage** and **bone.**

AREOLAR TISSUE.—Areolar tissue, sometimes called "connective tissue proper," acquires the former name from

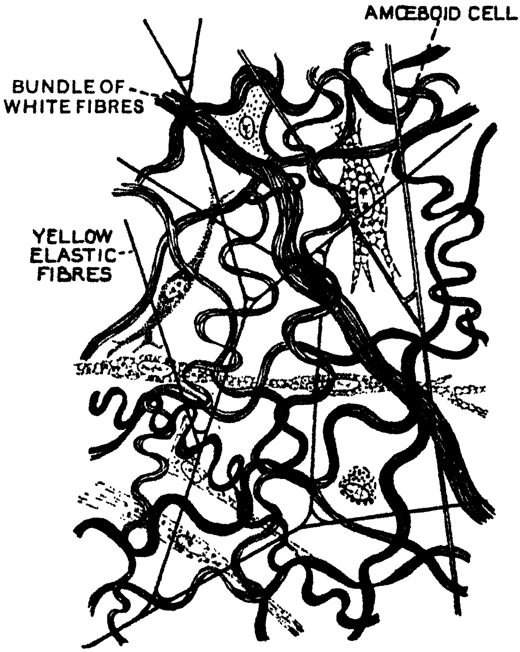


Fig. 185. AREOLAR CONNECTIVE TISSUE.

its appearance. It forms the white glistening substance found immediately beneath the skin in rabbit. This can be spread on a slide in a salt solution tinged with neutral red or cresyl blue. It contains cells, some of which are amoeboid while others help to make a membrane similar to pavement epithelium, together with two kinds of fibres

(Fig. 185). **White fibres** lie parallel to one another in bundles and follow a wavy course. They swell with acetic acid. **Yellow elastic fibres** pursue a straight course and anastomose with one another, coiling up if broken. White fibrous tissue is specially developed in the tendons. Yellow elastic tissue is predominant in the ligaments, arteries, and to a lesser extent the veins.

Lymphoid Tissue.—In lymphoid tissue the white fibres are continuous with a very fine network of fibres of similar character. In the meshes of the network a fluid is present instead of the mucoid substance of other areolar tissues. The cells wrap round the fibres thus tending to hide them.

Adipose Tissue.—In adipose tissue there is a large amount of fat. This tissue is very widely distributed, it

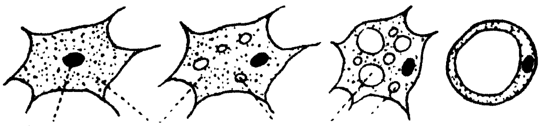


Fig. 186. Development of a Fat-Cell.

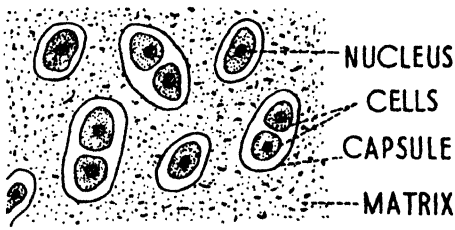
is essentially areolar tissue in which the cells are large, ovoid, full of fat (Fig. 186), and usually found in groups. It serves not only to store surplus material, but it also forms soft, elastic cushions for nerves, blood vessels, kidneys, etc.

In embryonic connective tissues the ground substance is the most obvious part, and is called Wharton's jelly, after its discoverer.

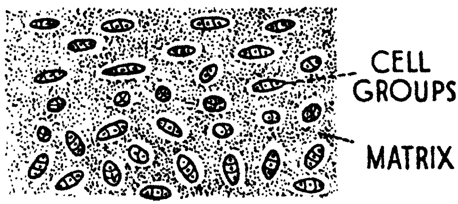
Cartilage.—Cartilage is familiar to all as gristle, and is bluish or yellow in colour. It is very strong, although light and elastic.

Cartilage may be the permanent framework of the body, as in the dogfish, or it may be the framework preceding bone formation, as in the rabbit. Permanent cartilages occur in the articular cartilages at the ends of bones, the

inter-articular cartilage, costal cartilages of the skeleton of the thorax, external ear, Eustachian tube, end of the nose, larynx, windpipe, bronchi and bronchioles. The ground substance, or matrix, is firm, elastic, translucent, composed of chondrin, and permeable to lymph, from which the cells obtain nourishment. The cells may occur singly, but more usually in groups of two or more (Fig. 187). In the matrix a line called the capsule can usually be seen surrounding the group. Each cell has its own capsule, and a capsule also surrounds a group. The matrix may or may not contain fibres; when it does not it is said to be hyaline.



HYALINE CARTILAGE



ARTICULAR CARTILAGE

Fig. 187. SECTIONS OF CARTILAGE.

Hyaline Articular Cartilage.—In Hyaline Articular Cartilage the groups of cells are flattened at and near the surface, with which they lie parallel, after the fashion of stratified epthelia.

Hyaline Costal Cartilage.—In Hyaline Costal Cartilage the surface cells are flattened and parallel to the surface. The deeper cells are in larger groups and contain fat, the matrix is granular due to deposition of calcium salts.

White Fibro-Cartilage.—In White Fibro-Cartilage the matrix is permeated with white, wavy fibres, lying parallel near the surface, but irregularly placed in the deeper layers. This tissue occurs in the inter-articular discs.

Yellow or Elastic Fibro-Cartilage.—In Yellow or Elastic Fibro-Cartilage the matrix is permeated with elastic fibres. This forms the external ear, Eustachian tube, and epiglottis.

All the cartilages, except those of the joints, are covered by a membrane of white fibrous tissue containing blood vessels. This is called the **perichondrium.**

BONE.—Bone is the strong, rigid tissue of the body. It consists of connective tissue with a deposition of calcium salts, chiefly phosphate and carbonate, making as much as 66 per cent. of it. When the mineral matter is dissolved out by dilute acid the remaining tissue is soft and flexible and yields gelatin on boiling.

Bone, except at the joints, is covered with a membrane, the **periosteum,** in the meshes of which there is a rich supply of blood vessels and nerves, which send branches into the bone substance. Adjacent to the bone is a layer of cells for building the bone and repairing it if damaged.

Bone may be compact or spongy. Bones of the skull have external and internal layers of compact bone with spongy bone between. The heads of long bones, *e.g.* the femur, consist of a thin external layer of compact bone with spongy bone inside. All bone is full of holes. The small ones in compact bone called **Haversian canals** (Fig. 188) are short and join obliquely; they carry blood vessels, lymph vessels, and nerves through the bone to the medullary spaces. Each canal surrounded by concentric layers of bone, called **lamellae,** constitutes a Haversian system; other lamellae lie parallel with the surface of the bone. Here and there between the lamellae are cells called bone **corpuscles.** The spaces in which these cells live are known as **lacunae.** Much smaller

channels, **canaliculi,** contain the protoplasmic threads which connect the cells with one another and the ground substance. The spongy, or **cancellous,** bone contains marrow. It consists of connective tissue in the meshes of which are masses of free cells, and adipose tissue.

The majority of the bones are formed by the **ossification of cartilage.** The form of the bone is made in the embryonic stage in cartilage, in which growth occurs at each end. The oldest cartilage cells are therefore in the middle; and ossification, or the change to bone, commences here. The cells under the periosteum multiply and invade the cartilage at right angles to the length of the bone. These cells are

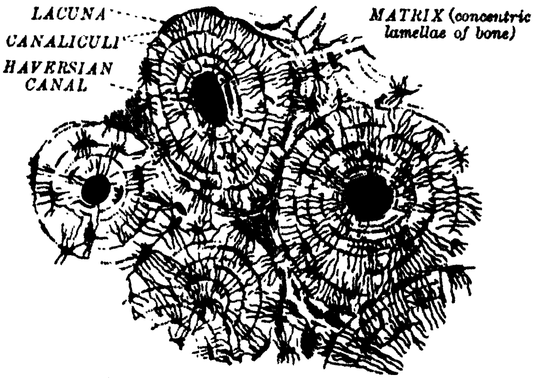


Fig. 188. TRANSVERSE SECTION OF BONE.

large multinucleate cells, called **osteoclasts,** which destroy the cartilage matrix. Small uninucleate cells, the bone-builders, are called **osteoblasts.** Before active destruction of cartilage occurs the osteoblasts form a thin strip of bone, the **periosteal bone,** close to the periosteum. With these two types of cells blood vessels also invade the cartilage, and the osteoblasts settle round them and proceed to make the Haversian systems. Usually the first structures built are destroyed and replaced. Osteoblasts caught in the bony structures they build, form bone corpuscles.

The roof of the skull and some other bones are formed by the **ossification of a membrane.** The membrane at first is a kind of connective tissue with very little matrix; the tissue corpuscles after a time secrete calcium salts, between the white fibres. The final structure is very like cartilaginous bone.

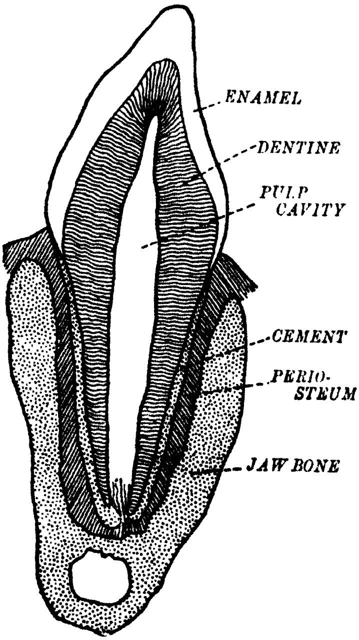


Fig. 189. STRUCTURE OF TOOTH. (After Klein.)

The Teeth.—The main portion of teeth in mammals consists of **dentine,** a tissue resembling bone, except that the cells comparable to osteoblasts, called odontoblasts, form a continuous layer and deposit their secretion at their outer ends only. Within the dentine is a " pulp cavity " (Fig. 189). This resembles the marrow cavity of bones and contains connective tissue, blood vessels, and nerve fibres. The portion in the jaw is coated with cement, but the tooth is capped with a very hard secretion, **enamel,** which contains the same substances as bone, but very little organic matter.

In the incisor teeth of the rabbit, which continue to grow in length throughout life, the pulp cavity is always wide open, so that the odontoblasts continue to receive food. In the cheek teeth this cavity is gradually constricted at the base, and as the food supply is cut off, the teeth cease to grow.

4. MUSCULAR TISSUE

Muscular tissue is the tissue which brings about movements of different parts of the body. There are two kinds:—

1. STRIPED MUSCLE.—This occurs where rapid movements take place. This may be **skeletal muscle** composed of long unbranched cells, found in the voluntary muscles that move the skeleton. A single muscle may be composed of few or many fibres, and is usually much longer than it is broad. Covering the whole is a sheath, the epimysium, which may contain blood vessels and fat cells. Branches

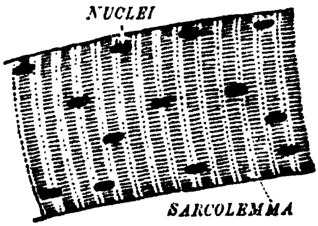


Fig. 190. PORTION OF A STRIPED MUSCLE-FIBRE.

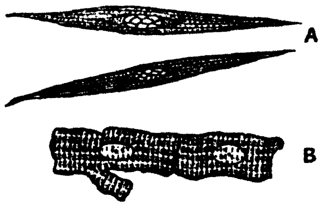


Fig. 191. MUSCLE-FIBRES. A, Unstriped; B, Cardiac. A large oval nucleus is seen in the centre of each.

of this sheath run in between the fibres of the muscle and divide them up into bundles. Each fibre is polygonal in transverse section, and it contains a very large number of nuclei. The body of the fibre appears granular, owing to a number of little rods or fibrils running in the protoplasm (Fig. 190). Each fibre is enclosed in a tough membrane, the sarcolemma, which is continuous with the tissue of the tendon. There is also a cross striation giving the appearance of alternately lighter and darker transverse discs.

The **cardiac muscle** of the heart is also striped muscle, although since the animal has no control over it, it is

involuntary. Here the cells are short and communicate with each other by means of short branches (Fig. 191). Each cell has one nucleus, which is usually oval in shape. There is no sarcolemma. The transverse striations of the protoplasm are not quite so distinct as in skeletal muscles. The cells are separated by septa, which stain with silver nitrate and are probably bridged by the fibrils, so that the cells are in communication with one another.

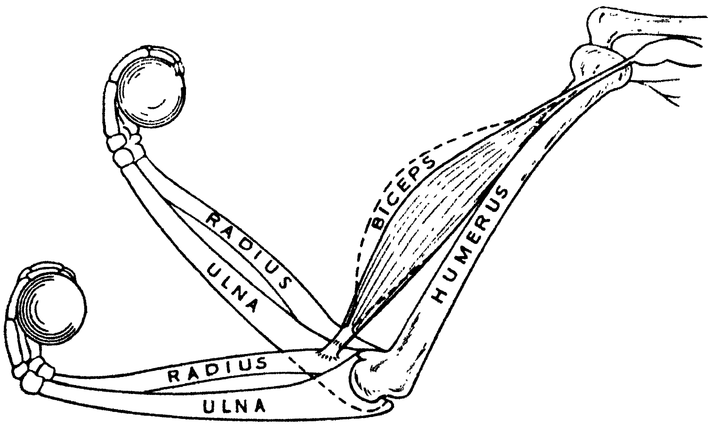


Fig. 192. MUSCULAR CONTRACTION.

2. UNSTRIPED MUSCLE.—Unstriped muscle, in which the cells have no cross striations, plays an important part in the walls of the alimentary canal, veins, arteries, bladder. It forms involuntary muscles. An unstriped muscle fibre is a very long, spindle-shaped, uninucleate cell (Fig. 191). These occur in bundles, either few or many being associated together.

The internal organs have muscular walls which contract and squeeze the contents, causing movement, as of the blood in the heart, the food in the alimentary canal. Muscle

action is familiar to all in the movements of their own limbs. The biceps muscle in the upper arm can be felt during movements, and the changes in it ascertained. This muscle is a mass of "flesh" tapering at the two ends where it is attached by tendons to the two bones, the scapula and radius (Fig. 192). When the arm is bent the muscle swells in the centre, this change of shape is called **contraction.** The muscle becomes shorter and thicker; there is no alteration in volume. The change in shape pulls the points of attachment nearer together and causes the arm to be bent. It is the muscle fibres which contract. The network of capillaries bring to them the necessary food and oxygen.

5. NERVOUS TISSUE

Nervous tissue consists of nerve cells and their processes, the whole unit being called a **neuron.** The cell body is large, containing one large nucleus, very granular protoplasm, and having one or many processes (Fig. 193). The latter may branch, and are spoken of as **dendrons.** One branch is different from the others, because it proceeds some considerable distance: it is called the **axon.** The cell body is alive and active, and the dendrons and axon keep it in, or bring it into, communication with other nerve cells or sense organs of the body.

Nerve cells may be:—

(1) Motor Cells.—These are found in the grey matter of the spinal cord, and activate the muscles of the limbs. They are star-shaped.

(2) Sensory Ganglion Cells.—These are round and unipolar because they have one process only, the axon, which branches into two (Fig. 193, B). One branch passes to the periphery of the body and the other to the central

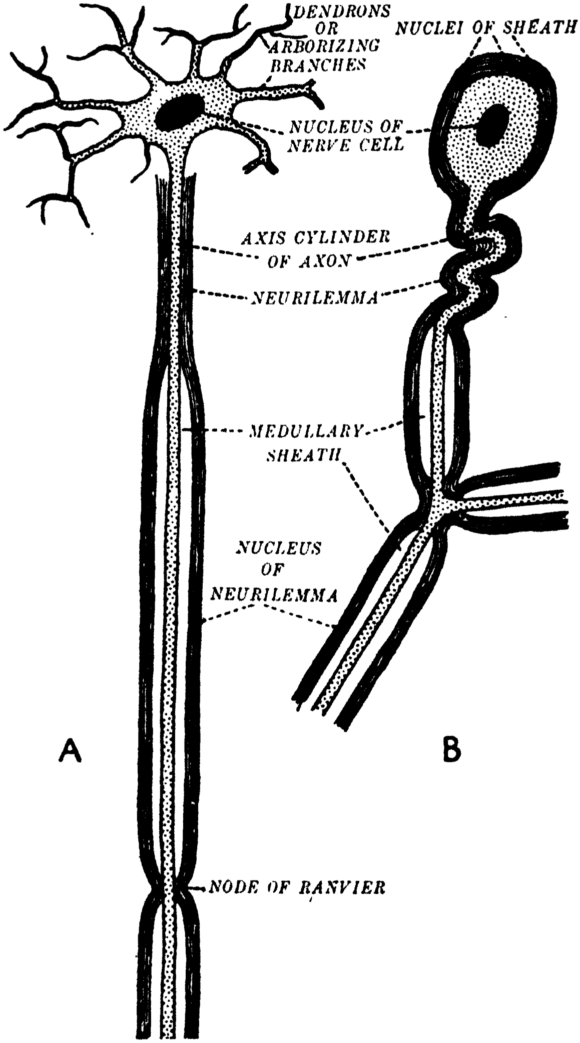


Fig. 193. NERVE CELLS.
(Partly diagrammatic.) A, Multipolar (from spinal cord); B, Unipolar (from spinal ganglion).

nervous system. In fishes these cells are bipolar, that is, have two branches.

(3) PYRAMIDAL CELLS.—These occur in the cortex of the brain. From the vertex of the pyramidal-shaped cell a long, branched dendron passes up towards the exterior of the cortex, other dendrons arise from the other angles and pass out horizontally. They are therefore multipolar. Dendrons branch from the base of the axon, which passes to the central nervous system.

(4) PURKINJE CELLS.—These are flask-shaped with a large axon and an enormous ramification of dendrons. They occur in the cortex of the cerebellum.

(5) SYMPATHETIC GANGLION CELLS.—These are star-shaped, with an axon and several dendrons. They may have two nuclei. The axon differs from that of the above-mentioned types because it has no medullary sheath.

When nerve cells occur in well-defined groups they are called **ganglia.** These may be either (1) Sensory Ganglia, or (2) Sympathetic Ganglia.

(1) *Sensory Ganglia.*—These occur close to the central nervous system. They are enclosed in a strong, fibrous, connective tissue sheath. Strands from the sheath divide the nerve fibres into groups. To one side of the ganglion are the nerve cells, around each of which is a spherical nucleated capsule continuous with the neurolemma.

(2) *Sympathetic Ganglia.*—These occur on the course of the viscero-motor nerves. They are smaller, the cells are scattered amongst the fibres, and many of the fibres are non-medullated.

Axons or **nerve fibres** may be large **medullated** or small medullated, the former belong to the skeleto-motor and sensory-motor nerves, the latter to the viscero-motor nerves. There are also **non-medullated** axons which are usually associated with unstriped muscles.

The medullated fibre has at intervals constrictions, called **nodes of Ranvier,** at varying distances apart. Each fibre is covered with a fine sheath, the **neurolemma,** in which, about midway between two nodes, is an oval nucleus. When a fibre is medullated there is a sheath of lecithin immediately within the neurolemma. This **medullary sheath** is interrupted at each node, and internal to it is a strand of apparently fibrillated tissue, the axis cylinder, which passes through the nodes and along the whole length of the axon (Fig. 193). At the junctions of the internodes a cement substance joins the neurolemma cells. A medullated fibre does not function before its sheath has developed, or if the sheath be damaged.

Nerve fibres can only convey a message in one direction; consequently they are classed as **afferent** when the direction of the message is towards the central nervous system, **efferent** when it is away from it, and **intracentral** when it is from one part of the central system to another. A nerve may consist exclusively of one kind of fibre, or it may contain more than one, when it is said to be mixed.

Afferent fibres end peripherally in sense-organs. Efferent fibres end in connection with muscle-fibres, gland-cells, and other active cells, conveying to them the necessary impulses. Efferent fibres are **motor** when distributed to striped muscles, **accelerator** or **inhibitor** when distributed to unstriped muscles, **secretory** when distributed to glands.

Motor Nerve Endings.—These are simple in unstriped and cardiac muscle. The fibre branches repeatedly and the fine branches end in bulbous extremities in close apposition to the muscle fibres. In voluntary muscles the branches eventually lose their medullary sheath and form a thin disc applied to the muscle surface.

Nerve Action.—A cross section of the spinal cord of rabbit (Fig. 194) shows a hole in the centre, the central

not affect the response, as no impulse may reach the brain until the limb is removed.

The nerves have been likened to telegraph wires because they convey messages from one part of the body to another. A nervous action such as we have considered is illustrated diagrammatically in Fig. 195. It is known as **reflex action** because the new impulse caused by the arrival of an impulse of feeling in the central nervous system travels back to a muscle. The diagram is drawn very simply, as only single cells and single axons are shown. The sensation received by **A** is known as a **stimulus.** Sometimes the nerve cell **B** may be in the brain instead of in the spinal cord. For instance, the nerves supplying the eye muscles arise in the brain, and they cause an animal to blink, that is move the eyelids, when anything approaches too near the eye. But although this is a nerve impulse from the brain, the movement takes place without any conscious thought, as we know quite well if we consider a similar incident happening to ourselves. It is an instinctive happening. We also can realise that things which at first may require much thought in order to perform them, such as walking and knitting, after much repetition become almost instinctive. We can do them automatically because we have acquired the habit.

6. BLOOD

Blood consists of a fluid matrix, known as the **plasma,** in which float a number of **free cells** (Figs. 121 and 151), the **white** and **red corpuscles.** The former in mammals are either **lymphocytes,** which may be large or small, and uninucleate, or **leucocytes,** which are amoeboid and have a nucleus possessing several lobes. The lymphocytes occur in lymphatic tissue; they digest and absorb fat. The leucocytes devour bacteria, just as Amoeba devours small organisms; for this reason they have been called phagocytes. They secrete anti-toxins, are concerned in uric acid meta-

bolism, and also in the clotting of blood. The red blood corpuscles in mammals are biconcave, non-nucleated discs containing **haemoglobin,** which is an organic compound containing iron. In the plasma of some of the lower animals **haemocyanin** is present instead. The function of the red corpuscles is to carry oxygen, which combines with the haemoglobin forming a bright red compound, oxy-haemoglobin, which readily decomposes and gives up the oxygen to oxidisable substances, leaving the blood much darker in colour. Variations in the form and number of the corpuscles have been noticed in the animals considered.

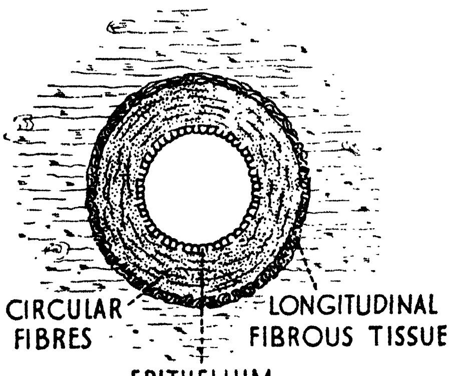


Fig. 196. Rabbit.
Transverse section of an Artery.

The plasma is composed of water, proteins, a small amount of carbohydrate, fats in a soluble form, salts, waste nitrogenous substances, gases, internal secretions or hormones, anti-toxins, and some enzymes.

The **clotting** of blood is due to the coagulation of the soluble protein, fibrinogen, into insoluble fibrin. This is done by the enzyme thrombrin, which is stored in the leucocytes as prothrombin. Clotting does not occur unless an activating enzyme, called thrombokinase, is also liberated. The latter is stored in the blood vessel wall; consequently when this is cut or injured thrombokinase is set free, and the thrombin causes coagulation. The presence of calcium salts is also necessary for this change to occur in mammals, but not in birds.

Marrow is either white or red. The former occurs in the shafts of long bones and contains a large number of fat cells, supported by a delicate connective tissue, in the spaces of which are leucocytic cells and cells resembling those in ossifying cartilage. Red marrow has less fat and contains red blood corpuscles.

7. VASCULAR ORGANS

Vascular organs are associated with all parts of the body. The **arteries** must have a smooth interior surface presenting as little resistance as possible to the flow of the blood within them. They must be very elastic and strong to resist pressures without bursting. They therefore possess a strong sheath of white fibrous tissue with the fibres rather loosely placed. Internal to this sheath is a layer of muscle fibres arranged circularly, with firm elastic tissue between them. The inner coat consists of elastic fibres forming a network and pavement epithelium, making the inner surface to the artery (Fig. 196). The **veins** are similar, but they have thinner walls and larger lumen, less muscle, and less elastic fibrous tissues.

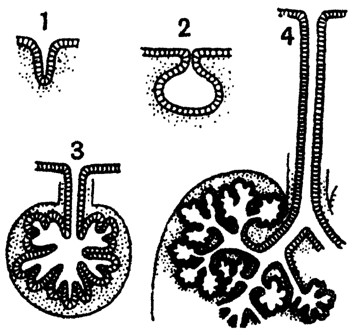


Fig. 197. STRUCTURE OF GLANDS. 1, simple pit; 2, flask-shaped gland with short duct; 3, 4, more complex compact glands. Vascular tissue dotted. (After Huxley.)

The **heart** has an internal epithelial layer, the endocardium, which lines the cavities; a thick middle layer of cardiac muscle cells, the myocardium; and an external layer, the pericardium. The endocardium consists of pavement epithelium on its inner side, and connective tissue with white and elastic fibres, and sometimes adipose cells

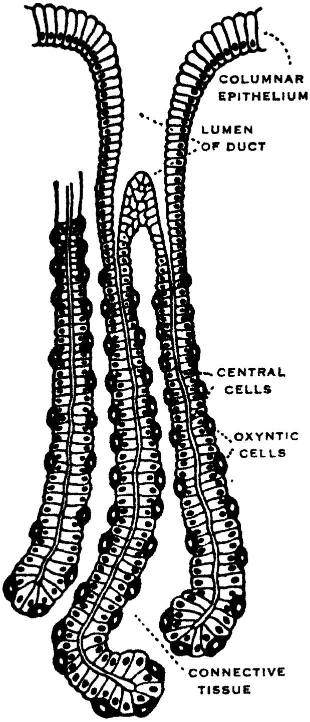


Fig. 198. Simple Glands in Wall of Cardiac Stomach. (After Klein.)

and plain muscle fibres. The pericardium internally consists of loose connective tissue containing a large number of blood vessels and fat cells, next to this the tissue contains bundles of white fibres and of elastic fibres, outside is a thin membraneous layer.

8. GLANDS

Glands can be classified broadly into:—

(1) Those which possess ducts opening:—(*a*) into a hollow organ, *e.g.* the digestive tract; (*b*) on the exterior of the body, *e.g.* sweat glands.

(2) Those which have no obvious ducts. They may have:—(*a*) fixed cells as the essential part, *e.g.* the thyroid gland; (*b*) free cells, which play a large part, *e.g.* the spleen.

Glands of the Digestive Tract.—The simplest consist of a number of cells around a central tube, and are found in the large intestine. More often the alveolus is branched (Fig. 197). The glands of the large intestine show two kinds of cells, some with small, oval nuclei, and others which are swollen and glossy in appearance owing to the production of mucous material, which they secrete. At the cardiac end of the stomach the glands are branched (Fig. 198). At the mouth of the glands the cells are tall and columnar with oval nuclei. Below the branching, the lumen

narrows considerably and two types of cells are present, the chief or central ones being wedge-shaped with oval nuclei. Outside these are some egg-shaped oxyntic cells

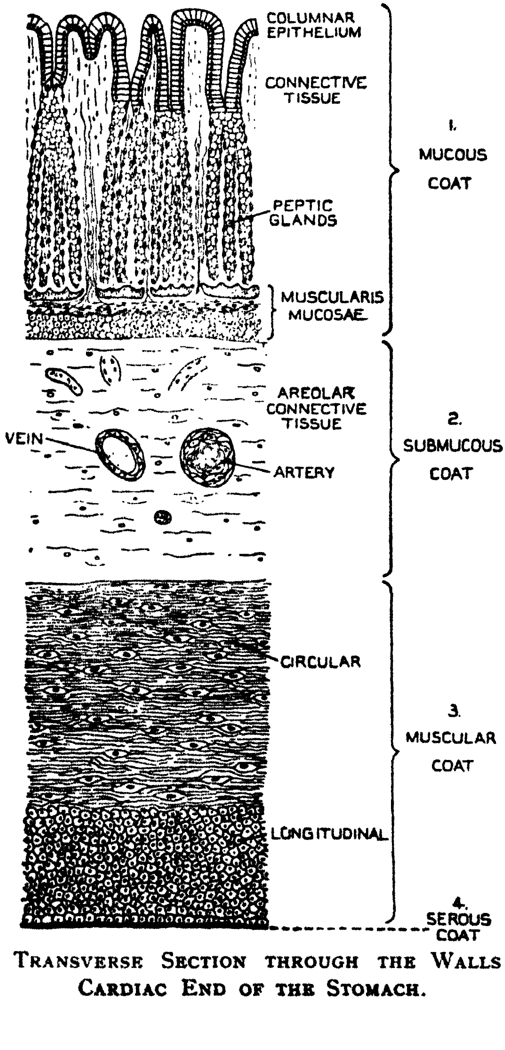


Fig. 190. Transverse Section through the Walls of the Cardiac End of the Stomach.

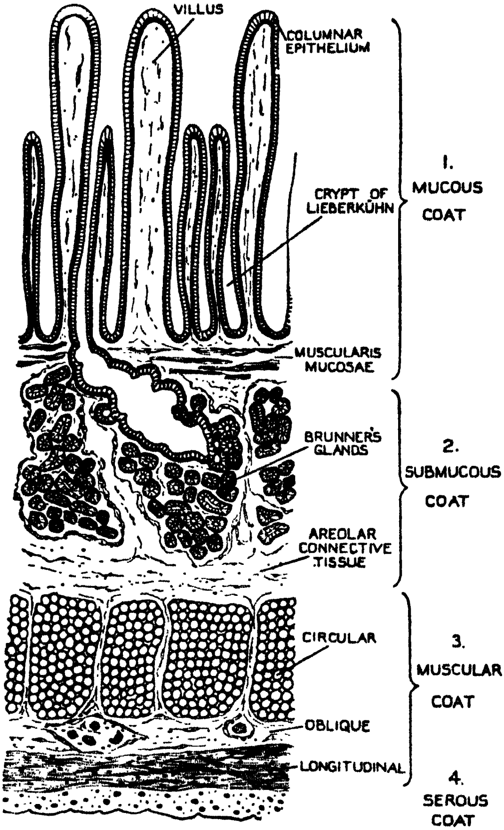


Fig. 200. LONGITUDINAL SECTION THROUGH WALL OF DUODENUM.

with smaller nuclei and less granular protoplasm. The central cells secrete the gastric juice and the oxyntic cells secrete the hydrochloric acid.

The **wall of the alimentary tract** is divided into four layers (Fig. 198):—

(1) The inner, mucous layer, or coat, consisting of columnar epithelium, a layer of connective tissue richly

supplied with blood vessels, a layer of unstriped muscle fibres which tend to encircle the tract, and a layer placed longitudinally. The double layer of muscle fibres is called the muscularis mucosae. Where glands are present, such as the **peptic glands**, the epithelium is sunk down into the connective tissue (Fig. 199). Where villi are present the connective tissue runs up into them (Fig. 200).

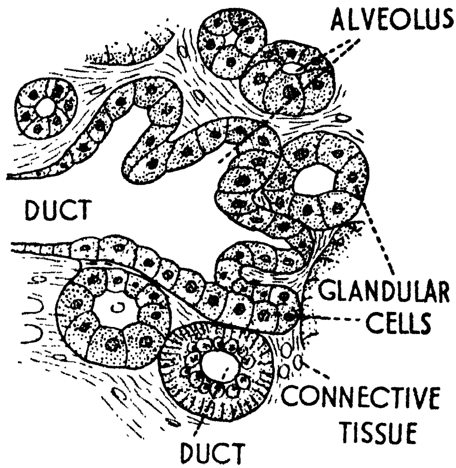


Fig. 201. RABBIT.
Piece of Salivary Gland. (Highly magnified.)

(2) The submucous coat consists of areolar connective tissue containing blood vessels, lymphatics and nerve fibres.

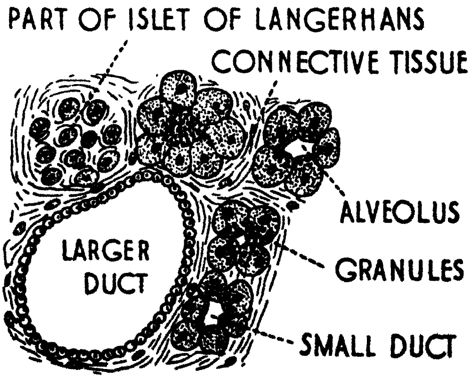


Fig. 202. RABBIT.
Small piece of Pancreas. (Highly magnified.)

(3) The muscular coat resembles the muscularis mucosae, but is much thicker. It is these layers which cause the peristaltic movements by means of which the food

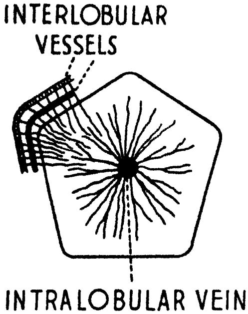


Fig. 203. Diagram of the Blood-Vessels of a Lobule of the Liver.

is passed along. Between the two layers of muscle fibres is a layer of nerve fibres.

(4) The serous coat consists of tesselated epithelium and is continuous with the mesentery.

In the pyloric part of the stomach there is very great development of the muscular coat. In the small intestine between the villi are simple unbranched glands, the **crypts of Lieberkühn.** The latter, together with **Brünner's glands** present in the duodenum, secrete the succus entericus (Fig. 200).

The Salivary Glands.—Some of the glands are **compound,** *e.g.* the salivary glands. Here around the lumen of each alveolus are from four to eight wedge-shaped cells with spherical nuclei and granular protoplasm (Fig. 201). Each alveolus has a fine connective tissue membrane. They are all bound together by a slightly coarser membrane. The duct, into which the lumina of the alveoli open, is lined with columnar epithelium.

The Pancreas.—The pancreas contains alveoli and also islands of cells which have a large blood supply, known as the islets of Langerhans (Fig. 202). The former are concerned with the secretion of the pancreatic enzymes. The pancreas also controls the carbohydrate metabolism in the animal, and probably the islets play a part in this connection.

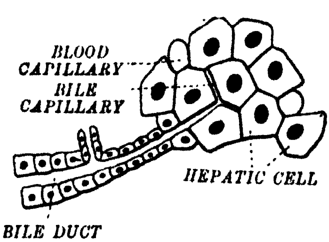


Fig. 204. Diagram of Structure of the Liver. (After Huxley.)

The Liver.—The liver is covered with a sheath of connective tissue, known as Glisson's capsule. It is composed of glandular substance and has a very large blood supply (Fig. 203). It consists of lobes, each of which has a duct. These join and form the bile duct. There is also the gall bladder, which is a reservoir for the bile, and this also has a duct which unites with the others. When food enters the duodendum the stored bile quickly flows out.

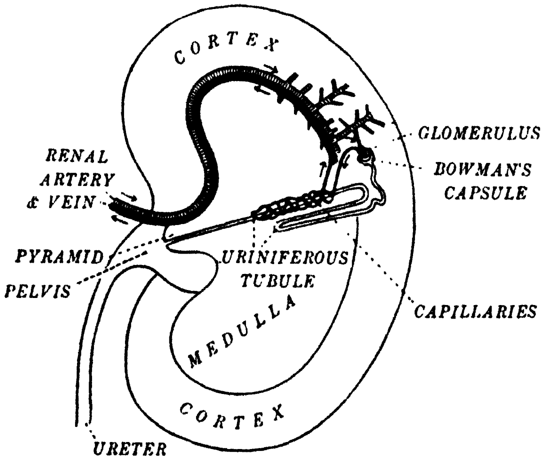


Fig. 205. Rabbit.
Diagram of Kidney.

The cut surface of the lobes of the liver show that it is composed of small polyhedral masses, the **lobules.** Each of these consists of a mass of nucleated cells with very small spaces between them, which are the ultimate branches of the bile-ducts. The liver cells, therefore, are the epithelial cells of these very narrow tubes (Fig. 204).

The liver secretes bile, regulates the amount of sugar in the blood, and changes the waste-products of the body into urea so that they can be removed from the blood by the kidneys.

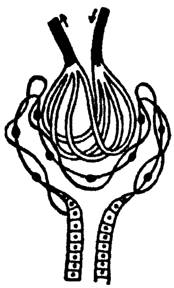


Fig. 206.
BOWMAN'S CAPSULE AND GLOMERULUS.

THE KIDNEYS.—The kidneys are a pair of compact glandular masses, from each of which the ureter leads to the bladder where the urine is stored between its periodic expulsions from the body. The kidney is divided into an inner portion, the medulla, and outer, the cortex. A median section of the kidney (Fig. 205) shows that where the ureter leaves the kidney its cavity expands into a large space called the pelvis of the kidney, and projecting into this space is the pyramid, a portion of the medulla.

The kidney is a mass of excretory tubules united together by connective tissue containing blood vessels. They are called **uriniferous tubules.** Each opens on the surface of the pyramid into the pelvis. In the other direction each ends in a **Malpighian body.** These bodies only occur in the cortex, where the tubules follow an irregular course. In the medulla they have a straight, radial course. The ultimate branches of the renal artery, which brings blood to the kidney, end, for the most part, in a little bunch of looped capillaries, called a **glomerulus** (Fig. 206). From this the blood passes to a network of

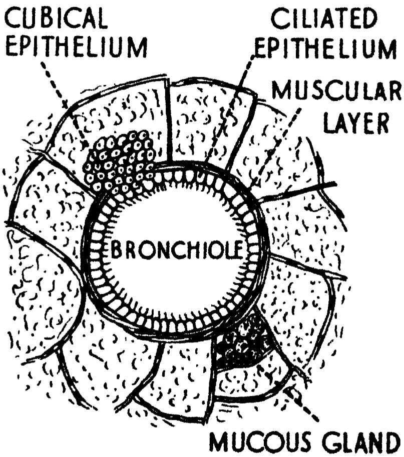


Fig. 207. RABBIT.
Section of small piece of lung stained with Silver Nitrate. (Highly magnified.)

capillaries around the cubical epithelium of the tubules and thence eventually to the renal vein. A Malpighian body is a double-walled capsule (Bowman's capsule) at the end of a tubule, containing a glomerulus.

As the blood passes through the glomeruli, water and salts (except phosphates) are drained off, as it circulates round the tubules, urea and phosphates are removed. The epithelium here is **excretory**; its function is to select materials already present in the blood, not to manufacture new.

Mucous Glands.—Mucous glands, either simple or branched, secrete upon the surface of the respiratory system. The **lung** consists of a number of lobules, separated by fine septa of connective tissue. Each is a system of air-sacs and bronchioles, traversed by arteries, veins, nerves, and lymphates (Fig. 208). The bronchioles, which are branches of the bronchi, have a lumen surrounded by a band of unstriped muscles, and possessing internally a ciliated epithelium (Fig. 207). The bronchioles lead into air-sacs, or alveoli, which consist of pavement epithelium surrounded by a fine membrane. Running between the alveoli are numerous capillaries.

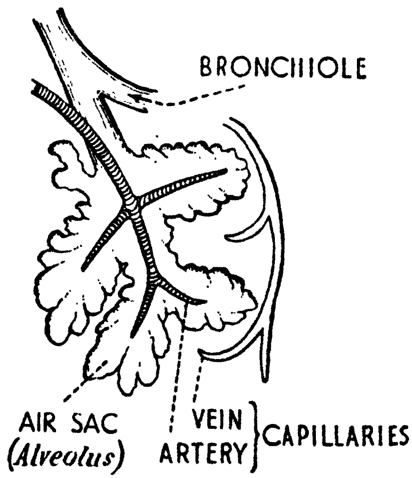


Fig. 208. Diagram to Show the Ending of a Bronchial Tube.

The Testis.—The testis is a compact body surrounded by a capsule of white fibrous connective tissue. That of the rat, amongst the mammals, is suitable for examination.

In transverse section a number of **seminiferous tubules** are cut across. Their walls consist of germinal epithelium, or spermatogonia. The cells of this layer divide so that the one remains in the outer row and the other becomes a spermatocyte, or **sperm mother cell**, which by reduction

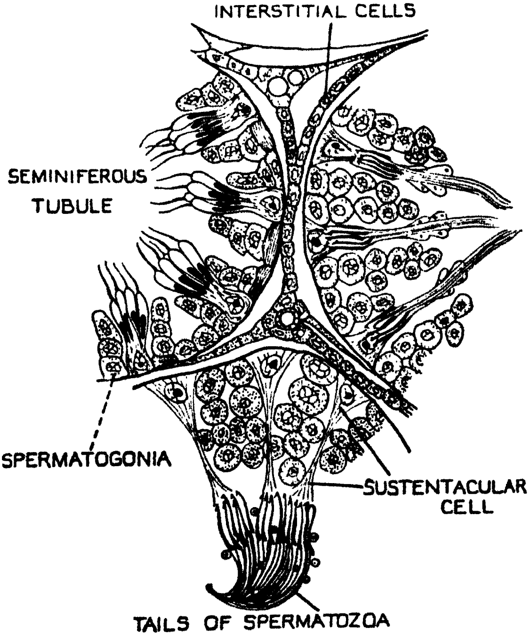


Fig. 209. Rat.
Section of Testis.

division forms four **spermatozoa** (Fig. 209). The spermatogonia may give rise to enlarged balloon-like cells, the sustentacular cells. These are well developed in the frog, and on these the developing spermatozoa are arranged, with their heads projecting into the deeper cells and their tails free in the lumen of the tubule. Between the tubules are **interstitial cells**, which secrete into the blood hormones

CHAPTER XIII

SENSES

1. INTRODUCTORY

In considering the lives of animals it has been noticed how they are sensitive to, or become aware of, their environment. Even an Amoeba becomes conscious of food substances, as distinct from solid bodies which are just obstacles in its path. This power of feeling occurs all over the simple surface of Amoeba. Some creatures have special sensitive organs, such as the tentacles of Hydra, the feelers of insects. The earthworm has special sensory cells scattered through its epidermis, by means of which it is very sensitive to contact; its sense of **touch** is very well developed. It is also very easily affected by vibration. It is quite sensitive to light, and it may be affected by vapours which affect the sense of smell.

As the scale of animal life is ascended and the brain and nervous system become more complex, so the number of stimuli to which response is made increases. Nerve-endings occur in the dermis of the skin (Fig. 210); these are very sensitive to the environment, and enable the creature to make adequate response to changes occurring round it, such as changes in temperature and moisture. These nerve endings are specially adapted in each case to suit the kind of situation in which the animal is normally found. The cnidocils of Hydra are its special sense organs. Fishes have neuromast organs, which consist of special sensory patches of the epidermis supplied by a special set of nerve fibres. They contain sense cells which bear short, stiff hairs. In the dogfish these patches are placed at the bottom of tubes in the skin filled with mucus. The most conspicuous occur in the lateral line. On the snout of the

dogfish there are the ampullae. Insects, prawns, crayfish, and some other animals have very specialised sense organs associated with their antennae.

2. THE SENSE OF SIGHT. THE EYE

In addition to the varying sensations received generally, more or less all over the body, there are certain special sense organs set apart to receive stimuli of a definite kind. The eye is the sense organ of **sight,** which is found in the vertebrates.

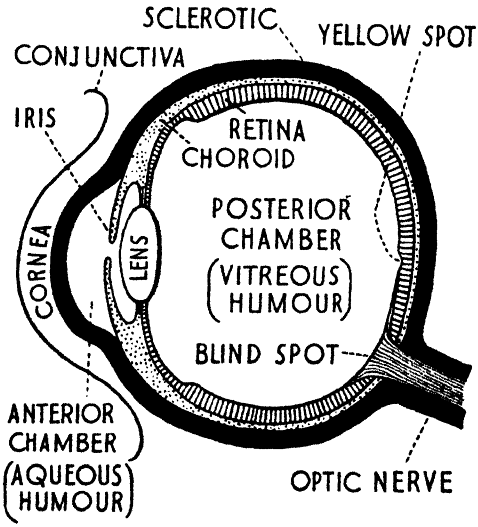


Fig. 213. RABBIT.
Diagram of median section of Eye.

The eye of a rabbit is a hollow ball filled with a transparent jelly. The coat of the ball has three layers to it (Fig. 213). The outermost one, the **sclerotic,** forms the white of the eye, but in the front it becomes transparent, and through it can be seen the coloured **iris** and the **pupil.** This transparent part is called the **cornea.** At the front of the eye there is a circular gap in the next two layers of the coat. The middle layer is the **choroid,** and it contains blood vessels; the gap in it is partly filled by the circular iris. The innermost layer is the **retina.** Immediately behind

the iris is a bi-convex lens. The round hole in the iris, the pupil, allows the light to reach the lens. The pupil naturally appears black as it leads into a dark chamber, the interior of the eye. The lens is hung on to the choroid by the suspensory ligament. The lens divides the eye into an **anterior** and a **posterior chamber.** They both contain jelly, or **humour,** but as this is more watery in the anterior chamber it is called **aqueous humour,** while that in the posterior chamber is **vitreous humour.**

Exp. Darken the room, take a lighted candle and place a bi-convex lens between it and a sheet of paper. The lens may be conveniently stuck into a cork so that it will stand. Move the sheet of paper, and when it is in the correct

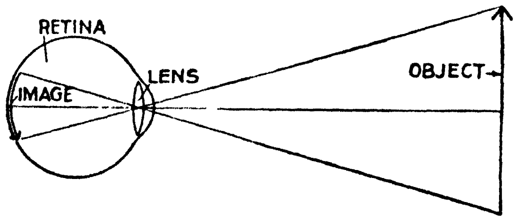


Fig. 214. Eye, Showing Formation of Image.

position, an inverted picture, or image, of the candle flame and top of the candle will appear on it. Observe that there is only one position when the image is really well-defined. Make a note of distances between candle and lens and between lens and paper, as these measurements will be needed later.

This image is formed because any light rays from the candle which pass through the lens are focused by it on the paper. Exactly the same occurs in the eye. Light rays from surrounding objects, on entering the pupil, pass through the lens and are focused on the retina (Fig. 214).

The retina is the most necessary layer of the eyeball. It is like a photographic film, or plate, in being sensitive to light, so that pictures of the surrounding objects are

formed on it opposite to the lens. The **yellow spot** (Fig. 213) is the centre of distinct vision. The layer of the retina nearest the choroid is composed of deeply pigmented, or black, tissue, in which are embedded the ends of the modified cells, known as rods and cones. It is these latter which are sensitive to light. Within this rod-and-cone layer is a layer of bipolar nerve-cells, and then a layer of larger nerve cells (Fig. 215). The axis-cylinders of the latter become the fibres of the optic nerve, which communicates with the brain.

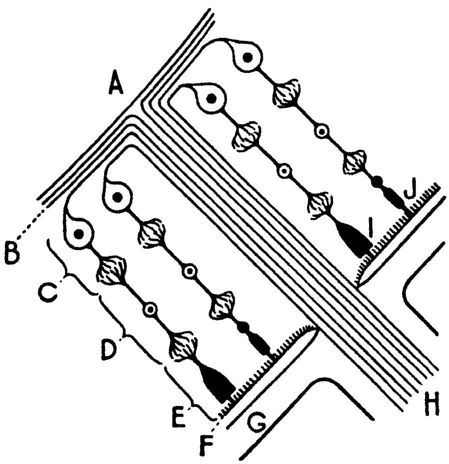


Fig. 215. STRUCTURE OF RETINA.

A, Vitreous humour; B, Nerve fibres, C Nerve cells (retina); D, Bipolar cells; E, Rods and cones (retina); F, Pigment cells; G, Sclerotic; H, Optic nerve; I, Cone; J, Rod.

The actual images formed on the retina are inverted, but owing to the intervention of the brain, things are seen right way up. The retina is interrupted by the optic nerve, and therefore there is a **blind spot** at this place.

In the experiment with a convex lens it was found that a clear image resulted only when the paper was the right distance from the lens. Yet the eye can see clearly things both near and at a distance. Obviously something has the power to alter in order to make this possible.

EXP. Repeat the previous experiment, using a thinner lens, and place the lens and paper at the same distance

from one another as when the thicker lens was used. Note that the candle must be moved further away than it stood in the previous experiment, to obtain a clear image.

Hence distant things are focused clearly on the retina by a thin lens, and near things by a thicker lens. The muscles attaching the lens to the choroid actually cause this alteration in the shape of the lens, thus altering its convexity and therefore its focal length, so that although the object is moved the image still falls on the retina.

It is well known that a cat's pupils are much larger in a dim than in a bright light. This is equally true for other animals and for ourselves. If the pupil enlarges, the iris becomes narrower; for the iris is like a blind which may be drawn across the window, the pupil, to permit only a little light to enter it, or drawn back to allow more light. It is a blind of an unusual shape, namely circular, but is comparable with the " stop " of a camera, or iris diaphragm of a microscope. The third cranial nerve travels to the muscles responsible for alteration in the lens and the iris and also to some of the muscles which enable the eyeball to move about in the socket.

A **lachrymal gland,** in the postero-superior angle of the orbit, or eye-socket, and a **Harderian gland,** in the antero-superior angle, secrete a watery solution. The corresponding solution in our eye sometimes forms tears. It enables the eye to move easily and also washes away dust. The latter process is helped by the movement of the eyelids over the eye in blinking. The excess secretion passes by ducts into the nasal chamber.

The eye is attached to its socket by a series of **muscles,** and thus it can move to alter the field of view. Four muscles are concerned with the horizontal and vertical movements of the eyeball and are therefore called " straight " muscles. They arise from the cranium just behind the exit of the optic nerve and are attached to

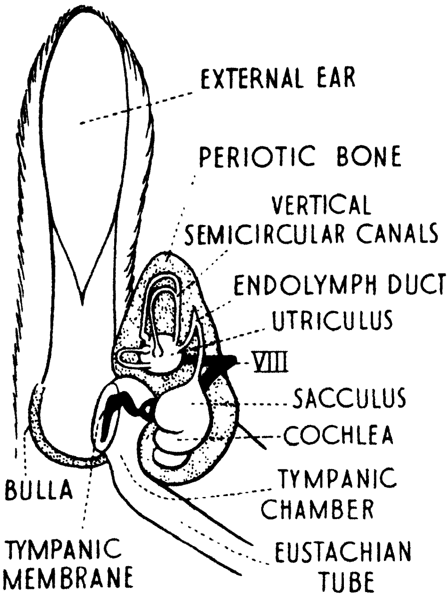


Fig. 216. RABBIT.
Diagram of Ear. The ear-ossicles and the auditory nerve are shown in black.

the upper, under, nasal, and temporal sides of the eyeball. They are known as the superior, inferior, anterior, and posterior rectus respectively. Passing obliquely from the front of the socket to the eyeball are the inferior oblique and the superior oblique muscles.

The eye, like all other parts of the body, is modified slightly according to the habitat and mode of life of the creature. Thus in dogfish the lens is globular and nearly fills the posterior chamber. This is a condition needed to help the animal to see through the water. Also associated with the aquatic habit is the absence of the glands. Both these modifications appear in an intermediate form in the frog, which is amphibious.

3. THE SENSE OF HEARING. THE EAR

The visible part of the ear, the **external ear,** is really the least important. Fig. 216 shows the part that is safely tucked away protected by certain bones of the skull. The essential part of the ear is the **internal ear,** which is enclosed in the **periotic bone** (Fig. 216). The

internal ear consists of two hollow bags, **utriculus** and **sacculus,** joined indirectly by a **Y**-shaped tube, the endolymph duct. The sacculus has attached to it a piece twisted like a snail shell, the **cochlea,** and the cells lining this have tiny hair-like threads of protoplasm projecting from them. The utriculus has attached to it three **semicircular canals,** two vertical and one horizontal, which are at right angles to one another. At one end of each canal where it joins the utriculus is a tiny swelling. The three swellings are shown in Fig. 216. They are called **ampullae,** and each is lined with cells having projections like those of the cochlea All this part of the ear is called the **labyrinth,** and it contains a fluid known as **endolymph.**

The **ear drum** is protected by a bone, the **bulla,** and this largely covers the periotic (Figs. 171, 172). It consists of a **tympanic chamber** with a **tympanic membrane** stretched across it. Crossing the tympanic chamber is a chain of three small bones. The one touching the tympanic membrane has been likened in shape to a hammer, and is therefore called the **malleus.** Adjoining this is the anvil or **incus,** with the stirrup or **stapes** touching it. The stirrup reaches the sacculus, and where it touches this there is a space in the ordinary wall of the sacculus, the **fenestra ovalis** or oval window, across which stretches a very thin membrane.

The external ear or ear trumpet (Fig. 216) collects the sound waves from the air. These waves cause the tympanic membrane to vibrate. It is capable of picking up a multitudinous variety of vibrations corresponding to all the various sounds in the world. The vibrations set the chain of bones in motion, and these knock on the oval window, which therefore also vibrates in turn. Its vibrations travel as waves in the endolymph, and these waves affect the projections of the cochlea cells. These cells have branching round them nerve fibres, which combine to form the eighth cranial, or auditory, nerve,

and the varying rate of movement of the projections from the cells is interpreted as different sounds by the brain.

It is important that the vibrations of the tympanic membrane should not be interfered with by any wrong pressure being put upon it. On the side of it nearer the external ear it is subjected to atmospheric pressure and therefore this must be maintained on the opposite side. In order to bring this about, a passage, the **Eustachian tube,** leads to the pharynx, so that the middle ear is directly connected with the atmosphere. It is for this reason that a cold in the head, causing the nose to be blocked up so that air does not freely enter the Eustachian tube, causes deafness.

The ampullae cells are also affected by variation in the waves; they receive branches from nerve fibres and therefore convey impulses set up in the endolymph along to the auditory nerve, but they have a use quite distinct from the cochlea cells. The endolymph waves in the ampullae vary according to the position of the three semi-circular canals with regard to gravity.

This part of the internal ear therefore gives a sense of direction, and nerve impulses travelling from it to the brain, cause further impulses to be conveyed from the brain to various muscles, so that the balance of the body is maintained. In order to be efficient in this respect it has the three canals at right angles to each other, that is in three different planes. This is really the original function of the ear, which is much less complicated in animals lower in the scale of life. The balance of the body is important to all animals, but only those which have some association with the land and make sounds themselves are believed to be able to hear.

The frog with its amphibious habits croaks to its mate, but the ear is much less developed for receiving sound than that of the rabbit. There is no external ear and the

tympanic membrane is level with the general skin. Instead of a series of small bones across the tympanic cavity for the conveyance of the vibrations received by the membrane there is only one, the **columella** (Fig. 217). This is largely cartilaginous; it extends from the tympanic membrane to the fenestra ovalis in the cartilage enclosing the internal ear. The essential parts of the labyrinth are present. The utriculus and sacculus of the internal ear communicate

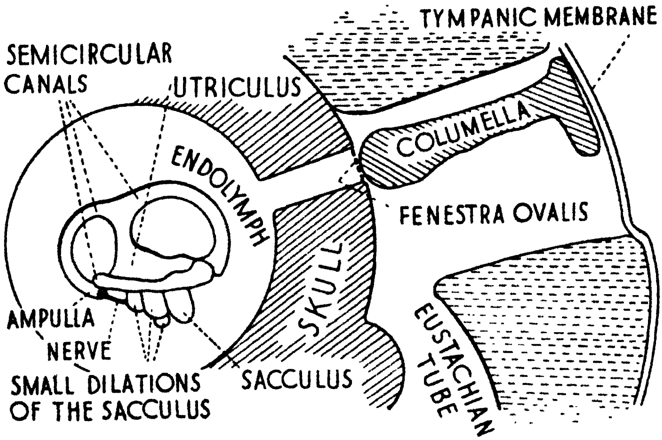


Fig. 217. FROG.
Diagrammatic Representation of Ear.

by a wide aperture. The endolymph contains some calcareous matter known as **otoliths.** The true organ of hearing is the sacculus. The semicircular canals enable the creature to keep its balance by judging the position of its head, and the otoliths are important in this connection.

The ear of the dogfish is simpler still, consisting only of the internal ear enclosed in a cartilaginous capsule; no ear drum is present. There is only a slight constriction to indicate the utriculus and sacculus (Fig. 105), and a very

small process at the posterior end is the only indication of the cochlea. The semicircular canals are well developed and there are many otoliths in the endolymph. Where the utriculus and sacculus meet a duct, the aqueductus vestibuli, runs to the top of the skull. Here the continuity between the external skin and that of the internal ear is maintained. In the higher animals as the ear develops it becomes entirely cut off from the external surface. All that remains of the aqueductus vestibuli in the rabbit is the endolymph duct.

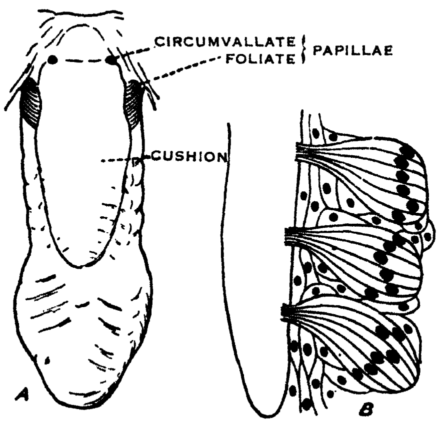


Fig. 218. Tongue of Rabbit.

A, Surface; B, Section through a fold of the Foliate Papilla, showing three taste-bulbs. (A, natural size, original; B, greatly magnified, after Klein.)

In crayfish, prawns, and other Crustacea, the auditory organs are two pear-shaped sacs, one of which is lodged at the base of each antennule and is open to the exterior, so that its development as an in-pushing of the skin is still more apparent. Grains of sand are usually present in this sac, and if iron filings are provided amongst the sand where the animal is living, they too will be introduced. Prawns that have acquired these iron filings in their antennules may be made to assume all sorts of positions with the aid of a magnet. These sacs are called statocysts. If they are removed the creature loses its sense of position and may swim upside down.

4. THE SENSES OF SMELL AND TASTE

Smells are perceived by cells in the lining of the nasal cavities. The nasal cavities are invaded by ingrowths from surrounding skull bones, and as all these are covered by a lining of cells, the surface sensitive to smell is thus increased in area. Some of the cells in this lining send out a fine thread of protoplasm to the nasal cavity. These threads are stimulated by vapours. Liquids which vaporise easily have a strong smell. The sensitive cells send down into the flesh of the nose axons which compose the fibres of the olfactory nerve, so that the sensation of smell is conveyed to the olfactory lobes of the brain.

Taste organs occur on the tongue. They consist of tiny oval groups of cells, known as bulbs (Fig. 218, B). These groups are collected in areas called **papillae** on the surface of the tongue. There are many of these around the tip, and two pairs of rather large ones at the back. The **foliate papillae** have ridges and furrows and the taste bulbs are in the furrows, while the **circumvallate papillae** are round with a groove containing taste bulbs surrounding them. Each cell of a taste bulb ends in a hair-like process and these touch nerve fibres, which convey any stimulus received by the cells to the brain. Only liquids will stimulate the taste bulbs. It is possible that different taste bulbs perceive different flavours.

CHAPTER XIV

CHEMICAL MESSENGERS OF THE ANIMAL BODY

1. INTRODUCTORY

In carrying out dissections of vertebrate animals glands have been found which have no definite duct, or outlet, to carry away the secretion that they make. Such glands are spoken of as ductless. They are also called **endocrine organs.** The substances they make are carried away by the blood stream in its circulation. These glands are very important, their normal functioning being quite essential for the general well-being of the creature. The substances they make are **hormones,** and they play the part of chemical messengers in the body. Here therefore is an additional system of communication to the telegraphic system of the nerves and brain. It is of vital importance to the animal that each and every part of its complex mechanism should work in harmony with all the rest, consequently the conveyance of messages is also of vital importance.

2. THE ISLETS OF LANGERHANS

A hormone is either a stimulating agent or it has an inhibiting action. The **Islets of Langerhans** in the pancreas are an endocrine organ, which produces the hormone insulin. This inhibits the too rapid convertion of glycogen, stored in the liver, to sugar. When insufficient insulin is being produced diabetes results.

3. THE THYMUS GLAND

The thymus gland (see pp. 173 and 215) consists of lobules containing both blood and lymphatic vessels. It is related to the formation of the genital organs, inhibiting their development until the body is sufficiently mature.

It also has a controlling influence in connection with other sexual characters, such as the antlers of deer, and the comb of the cock. It is most prominent in young animals. In hibernating animals it has a further function later in life, because as the hibernating season approaches it enlarges and becomes filled with reserve fat.

4. THE THYROID GLAND

The thyroid gland (see pp. 156, 179, and 233) has attracted a good deal of attention. It consists of two lobes, one on each side of the trachea, connected across by a narrow isthmus. It consists of highly vascular tissue and is encased in areolar tissue which sends into the vescicles strong, fibrous threads. Increased activity of the thyroid results in increased activity of the body tissues. It makes them greedy for oxygen. It also increases nitrogen metabolism. Tadpoles fed with thyroid mature very early. Excessive activity of the thyroid leads to over activity of the body; but efficient functioning is essential for the maintenance of health and vigour. An improved condition may result from feeding on thyroid gland obtained from another animal, by injecting an extract, or by grafting. If it is diseased or inefficient various stages of idiosyncrasies occur, the body may be malformed, general slowness of body and mind is evident, nervous and skin disorders appear. A substance containing a large percentage of iodine has been isolated from this gland and called thyro-iodin or iodo-thyrin.

The **para-thyroids** are four small bodies associated with the thyroid gland. In the lower vertebrates they are distinct bodies, but in the higher forms they become embedded in the substance of the larger gland. These produce a substance which neutralises the acid resulting from muscular activity, and consequently have a controlling influence on muscular metabolism.

5. ADRENAL BODIES

Adrenal bodies are associated with the kidneys (see pp. 179 and 231). They occur as islets in the kidneys in amphibians; in birds and reptiles they lie side by side, in mammals they are separated and rest by the kidneys. They consist of a soft, dark medulla, composed of a meshwork of fibrous tissue traversed by blood vessels and nerve fibres. This is surrounded by cortical tissue composed of columnar cells, and groups of polyhedral cells with lipoid or fatty globules. The whole is surrounded by a sheath of connective tissue. These bodies produce adrenalin. This substance, if injected in very small quantity into the web of a frog's foot, can be watched causing contraction of the blood capillaries. In mammals it causes an increase in the blood pressure. When injected into a cat, it had a similar effect to the arrival of a dog. The adrenal bodies play an important part in connection with the normal distribution and flow of blood, so vital to the maintenance of health and balance of bodily functions.

6. THE PITUITARY AND PINEAL BODIES

In the head are two such glands, the **pituitary body** and the **pineal body.** The former is quite essential to life. It has two lobes, the anterior one arising from the ectoderm of the buccal cavity, but quite soon cut off from the mouth, consists of large, granular cells with numerous blood vessels. If this lobe is inefficient diminution in limbs and bones of the face occurs. Giants have this lobe abnormally large. If young animals are fed with material from this gland the skeletal tissue develops very quickly. The posterior lobe is developed from the brain, but contains no nerve cells. In the cat and the dog it remains hollow, but more usually it becomes solid. It is thought to have some connection with the colour changes

which occur in some animals, such as chameleon, as environmental adaptation for protection. The pituitary body has a distinct connection with the arterial blood pressure and beating of the heart. It also plays an important part in connection with the formation of the genital organs. If a portion of the anterior lobe is removed early enough the sexual organs do not develop. In hedgehogs and dormice the action of the pituitary, as well as that of the thyroid gland, is damped down to prepare for the winter sleep. One very small injection will completely awaken a hedgehog in mid-winter.

The pineal gland consists of a series of tubes and small sacs surrounded by epidermal cells, and containing deposits of earthy salts, which have been called "brain sand." It is a prolongation of brain substance, associated with the optical centres. It is much more developed in certain fishes and lizards than in the higher vertebrates. It does not appear to have any optical function, but plays a part in connection with the growth of hair or fur and bone, and the balance of the body.

These are the most prominent and well-known endocrine organs. There are others, some of which are especially associated with reproduction. As we learn more about them, we find how tremendously important are the small parts of the body in maintaining the efficiency of the more obvious parts, and ultimately the life of the animal.

CHAPTER XV

EMBRYOLOGY

1. INTRODUCTORY

Embryology is the study of the development of the young plant or animal from the fertilised cell or zygote. It is very fascinating to study the development of any living thing from the stage in its life when all that it may

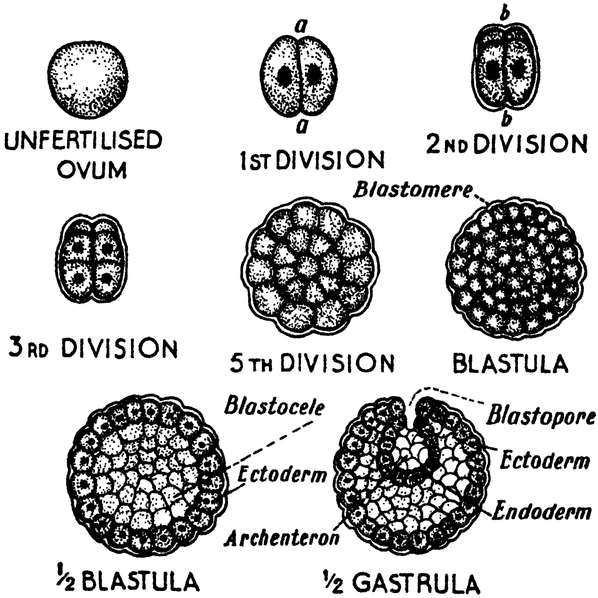


Fig. 219. DEVELOPMENT OF OVUM OF STARFISH.

become is wrapped up and hidden in the one cell resulting from sexual union. In the more primitive forms of life the gametes are similar, but as we ascend the tree of life they very soon become dissimilar. The female is a

relatively large, spherical, motionless cell. The male is smaller and actively motile. The female gamete of an animal is spoken of as the ovum or egg. This varies very much in size according to the amount of food, commonly called yolk, stored in its protoplasm. This determines very largely the extent to which the animal grows before it leaves the egg-shell. As soon as the head of a spermatozoon is completely plunged into the protoplasm of the ovum, a thin, flexible membrane, known as the vitelline membrane is secreted round the fertilised egg or zygote. This is the primitive egg-shell. The nucleus of the zygote contains chromosomes from both parents.

In the very simple forms of life, a few quite distinctive divisions are all that is needed to start the new life. As one ascends a little higher in the scale it is interesting how often, both in plant and animal life, eight cells are formed by three successive divisions at right angles to one another, as in Fig. 219. The original cell is divided into two vertically by *aa*, then into four by *bb*, also vertical, but at right angles to *aa*, and then into eight by a further division in the horizontal plane. In this way cells are produced in three planes thus providing ample opportunity for development in three dimensions. In animals these stages can be well seen in eggs of Echinoderms, *e.g.* sea-urchins, and starfish, some sponges, and the lancelet, *Amphioxus*.

2. ECHINODERMS

In Echinoderms the yolk is very small in amount, consequently the cells produced are very nearly equal in size, so that a very regular appearance results. By further divisions a ball of cells, known as the **blastula,** is formed. The cells are called **blastomeres** (Fig. 219). The ball becomes hollow to form the primary body-cavity, or **blastocoele.** Later one side of the ball becomes pushed inwards, converting it into a two-walled cup, the **gastrula,** with a wide opening, the **blastopore** (Fig. 219). The outer

layer, or wall, is the **ectoderm,** or **epiblast,** and forms the skin of the animal, the inner layer is the **endoderm,** or **hypoblast,** and forms the lining of the alimentary tract and its outgrowths. These constitute the first two germinal layers. The formation of these layers is known as invagination. The hollow constituting the primitive alimentary canal is called the **archenteron.** From the endoderm, pouches develop whose cavities at first communicate with the archenteron, but later the pouches become cast off from it and wedged between the endoderm and ectoderm. The walls of these cavities make the third germinal layer, or **mesoderm** and the cavities form the coelom. From these three layers all the parts of the body develop.

3. AMPHIOXUS

The ovum of Amphioxus is surrounded by a single layer of cells known as the **follicle,** which remains round it during early developments. This animal burrows in sand at the bottom of the sea and acquires its name because it is equally pointed at both ends, having no skull or brain. Fertilisation is said to occur about 7 p.m., and segmentation begins about an hour later. The egg is **microlecithal,** that is practically no yolk is present. The egg is spherical, but the presence of one polar body marks what is called the animal pole, while the other end of the axis is called the vegetative pole. The first and second divisions are vertical, the third horizontal. The cells formed are practically equal as in the echinoderm, and as in it all the substance of the ovum is divided; therefore the **segmentation** is said to be **equal** and **holoblastic.** Division continues until a hollow spherical blastula is formed of 256 cells.

The vegetative end of the sphere, which contains a few yolk granules, becomes flattened, then gradually pushed in or invaginated to form a gastrula (Fig. 220). This lengthens owing to the growth of the blastopore lip. The

growth is at first more rapid on the future dorsal side, later it extends to the ventral side, so that the blastopore becomes a small opening situated at what will be the hinder end of the body. The dorsal side then becomes flattened.

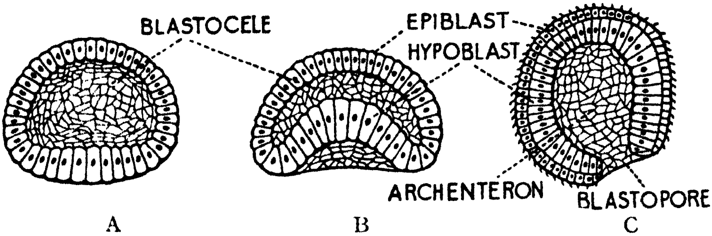


Fig. 220. AMPHIOXUS.

Section of Embryo. A, Blastula; B, early gastrula; C, later gastrula with ciliated epiblast.

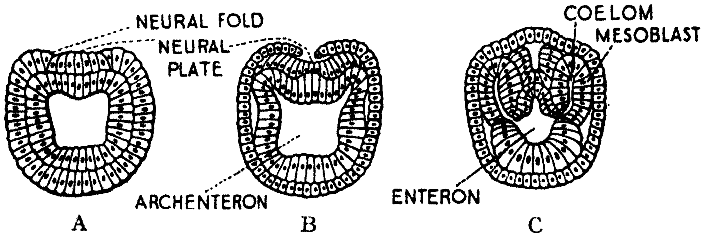


Fig. 221. AMPHIOXUS.

Transverse sections of Early Larva. (From Willey, after Hatschek.) In A, the outer layer is epiblast (with neural plate just differentiated on the dorsal side); the inner, primitive hypoblast. In B, the neural folds are seen; under the neural plate, the first sign of the notocord is seen, and on either side of it a myocoelomic pouch. In C, the neural plate has begun to roll up, the neural folds have closed over it, and the myocoelomic pouches are more distinct.

The epiblast becomes ciliated, and the gastrula revolves within the vitelline membrane; the follicle is broken through, so that the little embryonic body is free to swim in the sea and obtain a further supply of food. The cells on the flat dorsal side become more columnar forming a

distinct strip, the **neural plate**, which later forms the nerve cord. The epiblast becomes detached at the sides of this plate and grows over it enclosing a small space (Fig. 221). This growth begins at the hinder end and the blastopore now opens into this space. The neural plate folds upwards, meeting above the space to form a tube, which will become the nerve cord (Fig. 221). The hollow is the **central canal.** The blastopore, now known as the **neurenteric canal,** leads from the central canal to the alimentary tract; later it closes.

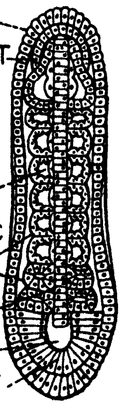


Fig. 222. AMPHIOXUS.

Horizontal section through a Lava in the middle of the notochord, with eight myocoelomic pouches on either side of it. (From Willey, after Hatschek.)

While this has been happening, the hypoblast beneath the neural plate has become folded to produce the **notochord** in the median position, and the **mesoblast.** The latter produces five folds, one median and the others paired laterally, which became the mesoderm. These folds become segmented into a series of pouches, the **myocoelomic pouches** (Figs. 222 and 223). The archenteron also develops to form the enteron and the hollows of the pouches.

Three germ layers are now present making Amphioxus a **triploblastic** animal. About eight hours after fertilisation, before this is all completed hatching occurs, that is to say the vitelline membrane is thrown off and the embryo has become a larva. When fully developed Amphioxus is a fish-like animal about two inches long and almost transparent.

It is interesting to notice that the general plan of the structure of the gastrula, with its two layered wall of cells

and central cavity open to the exterior by a terminal pore, resembles Hydra. Such resemblances are important because they provide a strong argument in favour of the theory of evolution.

In all vertebrate animals—

(1) The **epiblast** or **ectoderm** gives rise to:

(*a*) the epidermis covering the body and the enamel of teeth;

(*b*) the nervous system;

(*c*) the sensory epithelia of the special sense organs;

(*d*) the lens of the eye;

(*e*) the lining of the mouth and cloacal aperture.

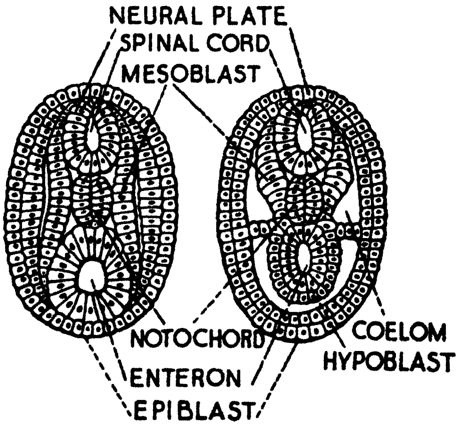


Fig. 223. AMPHIOXUS.
Diagrammatic transverse sections of a Larva. In A, the neural plate has completely rolled up to form the spinal cord; beneath it the notochord is distinct; beneath this is the mesenteron. The myocoelomic pouches are pushing their way between these structures and the epiblast, on either side.

(2) The **hypoblast** or **endoderm** gives rise to:

(*a*) the lining epithelium of the greater part of the alimentary canal;

(*b*) the epithelium of the liver, pancreas, and thyroid;

(*c*) the lining of the lungs and respiratory tract, gill pouches in fish.

(*d*) the notochord.

(3) The **mesoblast** or **mesoderm** gives rise to:

(*a*) the skeleton;

(*b*) the connective tissues;

(*c*) the muscles;

(*d*) the blood and lymphatic systems;

(*e*) the kidneys and their ducts;

(*f*) the generative organs;

(*g*) the epithelium of the coelom.

It will be seen that the primitive germ layers become very much modified in form and position during their development, also that some organs are derived from more than one of these layers.

4. THE FROG

The ripe ova of the frog are very much larger than those of Amphioxus; they are about $\frac{1}{14}$ of an inch in diameter. They have a considerable amount of yolk in the vegetative hemisphere. The protoplasm around the nucleus, which lies near the animal pole, contains a black pigment. The yolk being concentrated at one pole the ovum is said to be **telolecithal.** The ova are shed in their vitelline membranes, each being surrounded by a layer of albuminous substance secreted by the oviduct walls. They are fertilised by the males as they are laid. Segmentation begins as in Amphioxus, but is much slower owing to the yolk impeding the protoplasmic activities. The first and second divisions produce four similar cells, each with an upper, black pigmented region and a lower, white, yolky part. The third division produces four small, pigmented, upper and four large, yolky, lower blastomeres (Fig. 224). Segmentation is therefore said to be **holoblastic** and **unequal.**

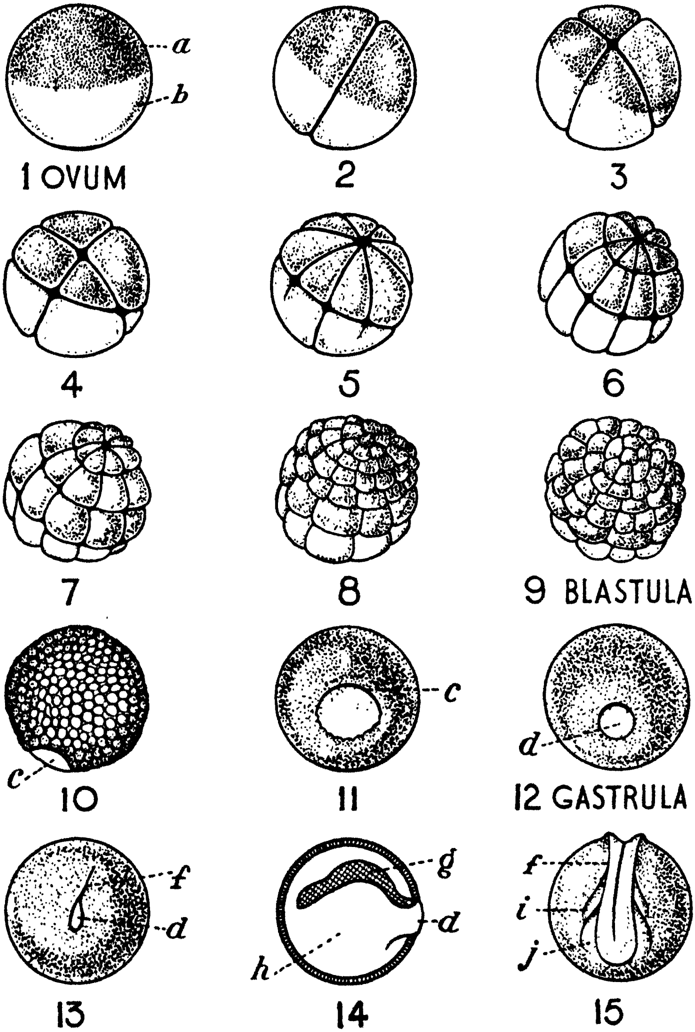


Fig. 224. Diagram of Embryology of Frog.

1-9, Cleavage into blastomeres; 10-12, Gastrulation; 14, Section of 13; *a*, Pigmented portion; *b*, White, yolky portion; *c*, Lip of blastopore; *d*, Yolk plug; *f*, Neural fold; *g*, Gut; *h*, Endoderm; *i*, Gill plate; *j*, Sense plate.

Divisions continue and the blastula is formed, of which the pigmented cells are the future epiblast and the yolk cells give rise to the hypoblast. Both portions differ from those of Amphioxus by becoming more than one cell thick.

From this blastula a gastrula is formed by the epiblast overgrowing the yolk cells. The blastula floats with the

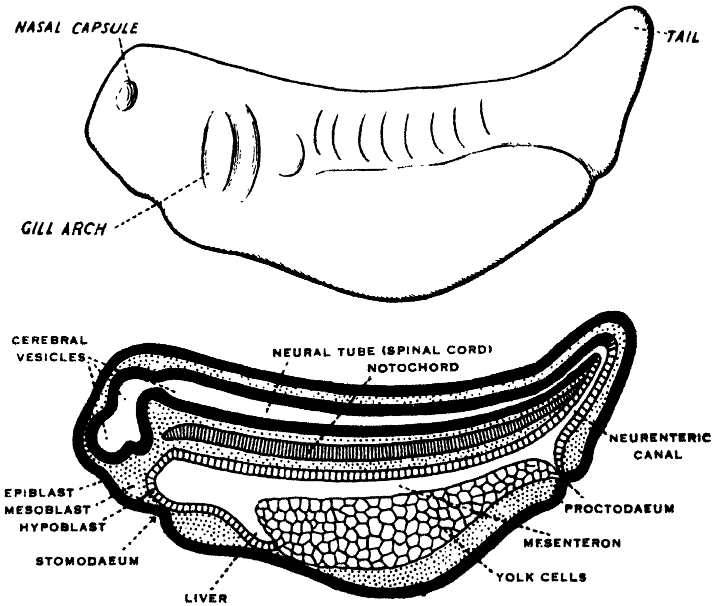


Fig. 225. FROG.
Median Longitudinal Section of Embryo. (After Howes.)

black epiblast uppermost; this grows over the yolk cells so that their exposed area becomes decreased. This growth is brought about by the division of cells at the circumference of the yolk to form separate small pigmented epiblast cells, and large inner cells. On one side of the white surface, just below the edge of the epiblast a small,

shallow, crescentric slit appears. When the growing epiblast reaches this an increased number of cells is formed on the black side of the slit, so that a fold, or lip, projects over the yolk cells on the other side enclosing a narrow space, the future digestive cavity, called the **mesenteron** (Fig. 225). The lip is the upper edge of the blastopore. The ends of the crescent lengthen and curve round to form a circle.

The yolk is gradually covered by epiblast cells except a small circular area, the **yolk plug,** at the blastopore. Eventually this also is covered and the blastopore is a slit. This closes in, first in the centre, then at the lower end, so that only the upper pore remains open, which later becomes the neurenteric canal. At the lower end a pit, the **proctodaeum,** is left in the ectoderm, in which the anus is formed later. In the central part between the proctodaeum and neurenteric canal a groove is formed, beneath which the epiblast, hypoblast, and mesoblast meet in a band of cells known as the primitive streak. Gradually the blastocele is obliterated and the mesenteron enlarged. From the thinner dorsal wall of the mesenteron, composed of yolk cells, the mesoblast and the notochord develop, the former by a splitting off of an outer layer of cells.

It will be noticed that differences which are mechanical and also adaptational occur between Amphioxus and frog, primarily owing to the presence of yolk. In frog the epiblast develops very early, and there is never any actual archenteron, with walls formed from the primitive hypoblast, to develop into the mesenteron and myocoelomic cavities. Instead these cavities both appear by the splitting of a solid mass of cells, and they are never connected. After the supplementary epiblast has been separated, the yolk cells correspond with the primitive hypoblast and, like that, form the hypoblast, notochord and mesoblast.

The split which forms the mesoblast starts on each side of the mid-dorsal line and forms a sheet round the developing alimentary canal, except in the mid-dorsal line where the notochord forms. On each side of this line the mesoblast is thicker than in other parts and forms the segmental plate. In it a split appears, the rudiment of the coelom. The two parts of the plate so formed are the outer, or somatic, layer and the inner, or splanchnic, layer. The segmented plate then divides into a series of blocks or **mesoblastic somites**, separating it from the lateral plates which do not become so divided (Fig. 226). The future dorsal surface becomes flattened to form the neural plate, the edges of which thicken, producing the neural folds which are continuous in front and join the side lips of the blastopore behind. At the anterior end, on either side of the neural plate, a thickening appears, which becomes divided by a furrow to form a gill plate and a sense plate. The neural folds meet to enclose the central canal, and since they enclose the blastopore, a neurenteric canal arises, but this soon disappears. Before the folds unite in front the walls of the open canal exhibit three swellings, the rudiments of the fore-, mid-, and hind-brains.

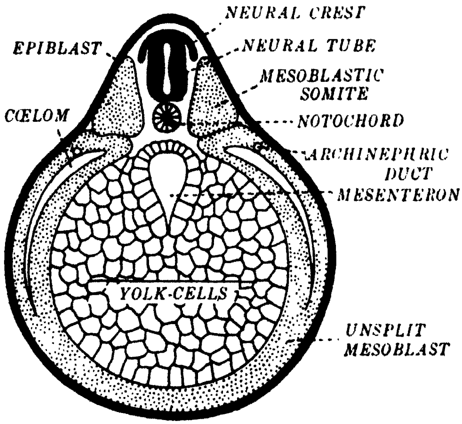


Fig. 226. FROG.

Transverse section of Embryo. (After Marshall.)

While this has been occurring the body has been elongating. Above the primitive groove a knob grows out to form the tadpole's tail. On each gill plate the visceral arches are marked out and on the first two branchial arches branched **external gills** develop. Below the head a

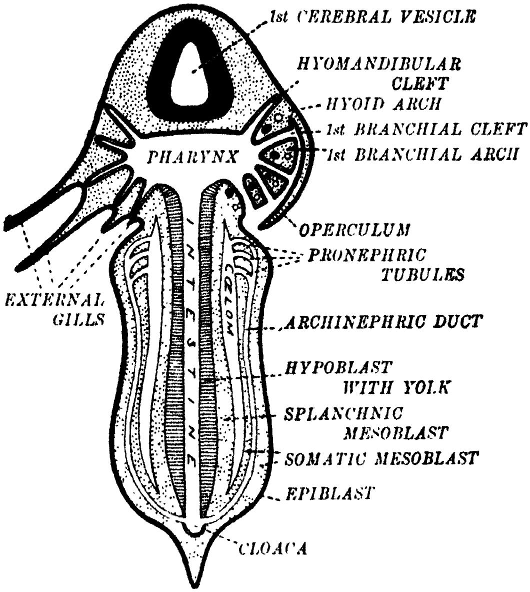


Fig. 227. TADPOLE.

Diagrammatic horizontal section showing a later stage on the right side than on the left. The black spots in the arches represent cartilage, and the white circles, arteries. (Partly after Marshall.)

median pit of epiblast forms the **stomodaeum**, which will later form the mouth. Behind it is a horse-shoe shaped sucker, and above it in each of the sense plates a pit, the future olfactory organ. When these changes are complete, about a fortnight after the eggs are laid, the animal hatches.

A third pair of external gills forms, the mouth opens, four gill-clefts appear. The external gills wither (Fig. 227) and a fold of skin, the **operculum**, grows over the clefts leaving a small opening for the discharge of water in breathing. The sucker or cement gland degenerates. After about six weeks the hind limbs appear at the base of the tail (Fig. 228), later the fore limbs become apparent. After about two months the lungs are formed and the gills start to degenerate; and about a fortnight later the tadpole begins to turn into a young frog. The outer layers of skin

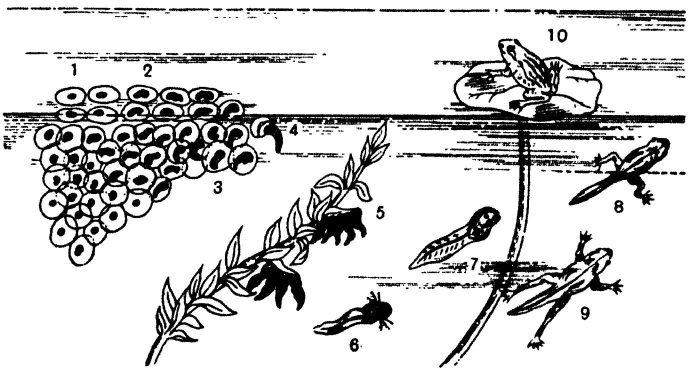


Fig. 228. FROG.

Stages in Life History.

and the horny jaws of the first mouth are thrown off. The mouth enlarges, and the tail shortens, completing the metamosphosis.

The first need for a vascular system arises because all the food is stored in the hypoblast, in what will be the intestinal region. The first blood vessels are formed in the splanchnic mesoblast and extend forward into the pharyngeal region where the heart develops. The first rudiment of an excretory system consists in the formation in the somatic mesoblast of a pair of longitudinal tubes, called the

archinephric ducts. At their anterior end three pronephric tubules are formed which open from the coelom by ciliated funnels, the nephrostomes.

5. THE CHICK

In the case of a bird, for example a fowl, the ovum is very large, containing a large supply of nutriment. In the egg not only is there a large supply of yolk within the vitelline membrane, but the ovum is surrounded by a further supply of proteins and salts in the " white " of the egg. This is protected by a double membrane and a chalky shell (Fig. 229). Between the membranes at the broad

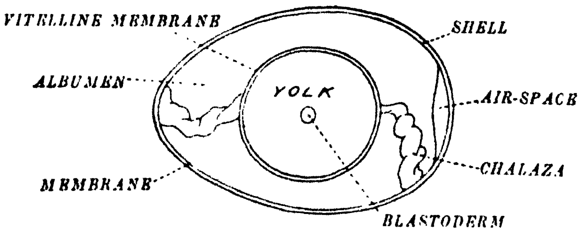


Fig. 229. DIAGRAM OF FOWL'S EGG AT TIME OF LAYING.

end of the egg an air space appears after the egg is laid. In the yolk a disc-shaped area, about $\frac{1}{8}$-inch diameter, is apparent, this is the **germinal disc** or blastoderm, which has developed before the egg is laid. The yolk is held in position by twisted strands of firmer albumen, the **chalazae,** so that the germinal disc is always on top. The shape of the egg is an adaptation to allow economical placing in a nest and also to prevent rolling away. The presence of such a large supply of food removes the need for a free larval stage; the young bird develops within the egg until it fundamentally resembles its parent.

Segmentation of the nucleus of the ovum, surrounded as it is by a mass of yolk-free protoplasm, begins so that two,

four, eight cells are formed and so on, but the whole ovum is not so divided. The divisions die off as they pass into the main mass of the yolk. Such partial segmentation is termed **meroblastic.** Many divisions occur before there arises in the horizontal plane a separation which cuts off an upper layer of complete cells which correspond to the primitive epiblast of the frog and a lower layer of nuclei surrounded by imperfectly defined cells merging into undivided yolk. Between the two layers a narrow segmentation cavity appears. Such is the structure of the blastoderm when the egg is laid. Later, divisions form round the lower nuclei, forming the primitive hypoblast and leaving a mass of yolk without any cell structure. The fall of temperature when the egg is laid stops further development for a time, until it is warmed by the bird's body, as she "sits" on it, or by incubation.

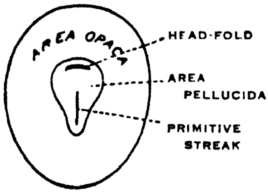


Fig. 230. BLASTODERM. Surface view, first day of incubation.

The blastoderm very soon shows a central **area pellucida** and an outer **area opaca,** the difference being caused by the lower layer being many cells thick near the margin, but only one cell thick in the area pellucida (Fig. 230), where also it is more distinctly separated from the yolk by the formation of a **sub-germinal cavity,** which corresponds with the mesenteron of the frog. There is a gradual passage between the two layers at one

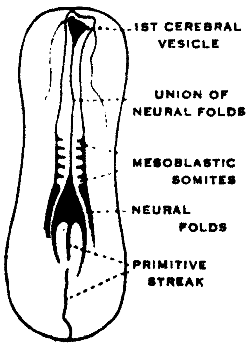


Fig. 231. BLASTODERM. Surface view, second day of incubation. (After Balfour.)

point in the margin, which marks the future posterior end of the embryo. The future dorsal region of the

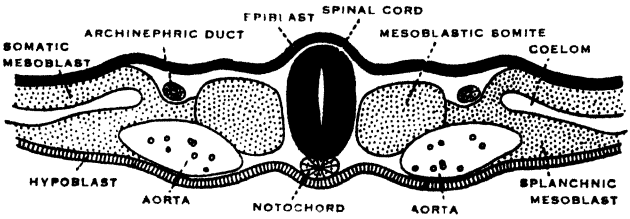


Fig. 232. BLASTODERM OF CHICK.
Transverse section, second day of incubation. (After Balfour.)

embryo is uppermost in the egg and the broad end of the shell to its left side.

The blastoderm, especially the area opaca, grows quickly over the surface of the yolk, covering half of it in two days, and later all of it. The embryo is developed entirely from the area pellucida, so that the chick differs fundamentally from the embryos previously considered in the utilisation of part of the ovum to form **extra-embryonic structures.** These are necessary because of the enormous size of the yolk, which cannot be included entirely within the embryo body.

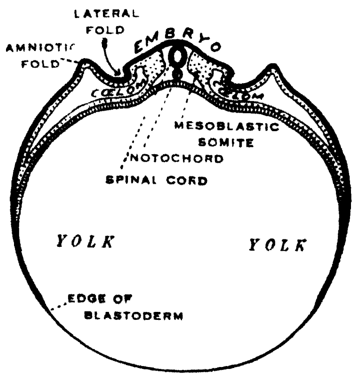


Fig. 233. EMBRYO CHICK.
Diagrammatic median section.
(First stage.)

The area pellucida gradually becomes pear-shaped, its broad end marking the future anterior end. At the

opposite end, where the epiblast and hypoblast merge together, very active division takes place. Gradually this point becomes drawn out to form the primitive streak, which represents the coalesced lips of the blastopore in frog, the cavity being eliminated by pressure due to the yolk. The primitive hypoblast becomes differentiated, part being hypoblast and part mesoblast. The extra-embryonic region of the latter is formed from the primitive streak, which also gives rise to additional primitive hypoblast and epiblast. The epiblast of the middle line in front of the primitive streak forms a neural plate, from which neural folds arise and extend behind, as in the frog. The notochord develops. The mesoblast splits to form the right and left portions of the coelom, but their union is delayed by the large mass of yolk. The splitting of the mesoblast is soon followed by the division into **vertebral** and **lateral plates**, the former soon dividing transversely into somites, beginning in the region just behind the head. These changes take place during twenty-four hours incubation by which time the blastoderm is about $\frac{3}{8}$ inch diameter (Figs. 231 and 232). From this time the embryo becomes more sharply delimited from the extra embryonic structures and begins to lose its flattened appearance. Figs. 233-238 help to show the gradual extension of the blastoderm (area

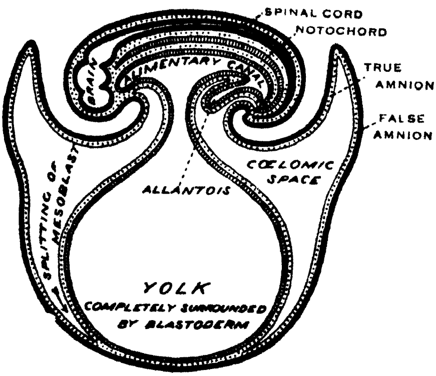


Fig. 234. EMBRYO CHICK.
Diagrammatic transverse section. (First stage.)

opaca) round the yolk, followed by the splitting of the mesoblast and the enclosing of the yolk in hypoblast and splanchnic mesoblast. They also indicate the gradual pinching-in by which the mesenteron becomes more and more separated from the yolk-sac, and how the epiblast and somatic mesoblast are tucked in ventrally to form a body-wall. In addition there are two new structures, the amnion and allantois.

Towards the end of the first day there appears in the blastoderm in front of the embryo a curved depression called the head fold; then other depressions appear known as the **tail fold** and **lateral folds.** In each case a parallel elevation, the **amniotic fold,** is formed. These gradually extend and unite, until the embryo is surrounded by two elliptical folds. The depression concerns both body wall and mesenteron, while the elevation consists only of the former. The depression gradually gets deeper and curves inwards to separate the embryo from the yolk sac; while the amniotic fold grows in height and curves to form a dome over the back of the embryo. This fold is hollow, the space it contains communicates with the coelomic space. The inner layer, with the epiblast towards the embryo and the mesoblast towards the cavity, is the **true amnion,** the outer layer with the epiblast outwards is the **false amnion.** The epiblast of the true amnion secretes, into the cavity between it and the

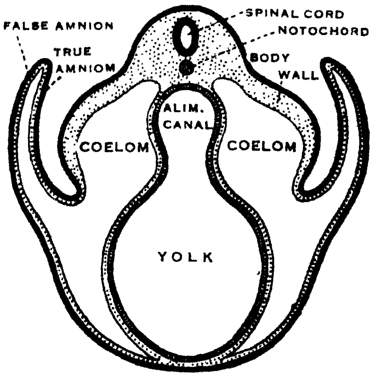


Fig. 235. EMBRYO CHICK. Diagrammatic median section. (Second stage.)

embryo, a fluid which acts as a cushion to protect the embryo from shocks. The false amnion later becomes completely separated by the absorption of the connection between it and the true amnion, and eventually forms a thin membrane just beneath the egg-membrane when all the albumen has been used. The membrane is completed by the serous membrane split off from the yolk-sac in that region, where the amniotic fold did not extend.

Very early in its development, blood vessels appear in

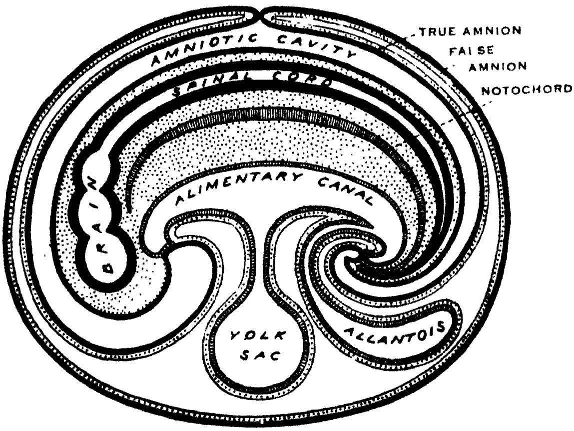


Fig. 236. Embryo Chick.
Diagrammatic transverse section. (Second stage.)

the area opaca to assist in the nutrition of the embryo (Fig. 239). Very soon also respiration becomes necessary; and as this is a land animal, gills would be useless. An outgrowth from the posterior end of the mesenteron, called the **allantois**, grows into the coelom, and thence into the space between the true and false amnion. This outgrowth consists of hypoblastic and splanchnic mesoblast, and in the latter blood vessels develop. In this way the blood is only separated from the atmosphere by a series of thin membranes and the porous shell.

The several systems of body tissues develop simultaneously. The development of the embryo proceeds more rapidly at the anterior end. The **fore-, mid,** and **hind-brain** are very soon apparent (Fig. 234). By the fourth or fifth day the rudiments of the chief parts of the brain can be seen. Later the peripheral nervous system arises from a series of paired outgrowths from the brain and spinal cord.

After about thirty hours' development the primary optic vesicles grow out from the fore-brain as a pair of lateral pouches. From these part of the **eye** (Figs. 239 and 240) and optic nerve will be formed. The lens originates from the epiblast.

After about thirty hours a pair of depressions of the epiblast appear on a level with the hind-brain. These are the **auditory-pits,** which are the beginning of the internal ear.

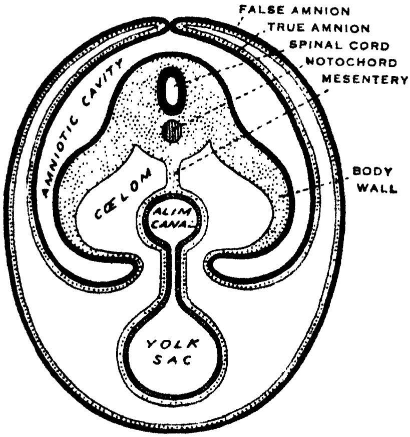


Fig. 237. Embryo Chick. Diagrammatic median section. (Third stage.)

The head develops more rapidly than the rest of the body and consequently bends down towards the yolk. After about forty-eight hours both it and the neck become distinctly curved towards one side (Fig. 239).

The primordium of the **heart** is in a very anterior position, and after about twenty hours' development, consists of a pair of endocardial tubes running longitudinally and joining posteriorly with a pair of vitelline veins (Fig. 239) which carry blood from the area opaca and the area

pellucida to the embryo. In these two areas irregular masses of cells become blood islands which later join to make a network of capillaries. The areas occupied by these capillaries are known as the area vasculosa. After about thirty hours' development the endocardial tubes fuse into a tubular heart, leading anteriorly into a pair of aortic arches; these pass forwards on either side of the digestive system, and then curve backwards to a position on either side of the notochord (Figs. 232 and 238). From the two aortic arches branches arise which are the vitelline arteries.

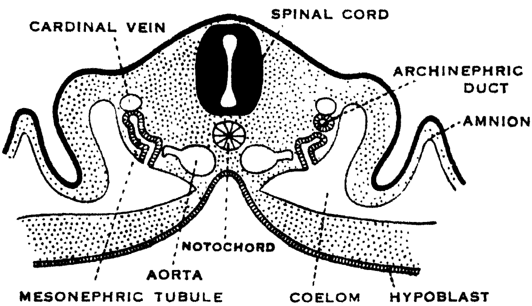


Fig. 238. Embryo Chick. Transverse section. (Third stage.)

At about thirty-six hours rhythmetical beats are occurring in the heart.

By the third day many of the essential body organs have started to develop, and on a level with the hind-brain gill-pouches are formed. These are paired outgrowths which form open passages from the fore-gut to the surface of the embryo. They are transcient and reminiscent of an aquatic life, and of special interest in connection with evolution.

The heart (Fig. 239) grows in length and becomes S-shaped. Gradually the beginnings of the auricle, ventricle, and conus arteriosus are apparent. By this time, however, the gill-pouches have been formed and two

extra pairs of aortic arches pass to the gill arches, later taking a dorsal and posterior direction they join to form the dorsal aorta. From the latter two large vitelline arteries pass to the area vasculosa. In addition to the two vitelline veins there is a pair of ductus Cuvieri bringing

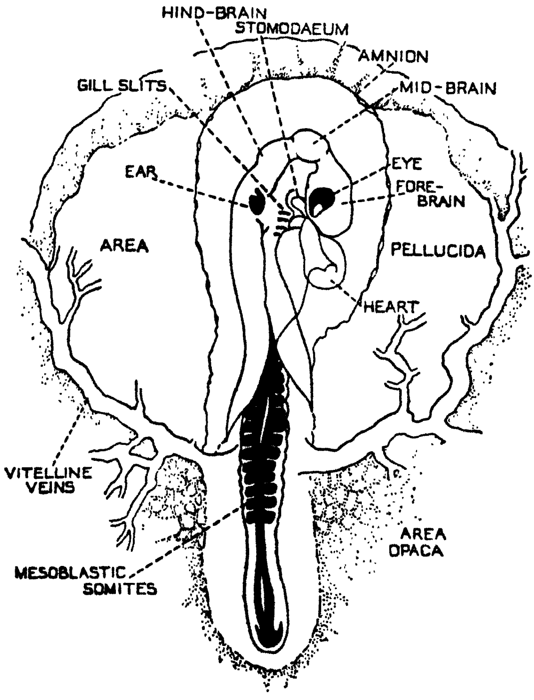


Fig. 239. Blastoderm of 72-Hour Chick. (Allantois removed.)

from the body of the embryo to the heart blood which they have received from the paired anterior and posterior cardinal veins (Fig. 238). At a later stage both the auricle and ventricle become divided into two, giving the heart the same form as in rabbit.

After about thirty hours' development there are twelve mesoblastic somites (Figs. 231, 232, and 239). From the dorsal side of the mass of cells which lie between the splanchnic and somatic layers (Fig. 231) on either side of

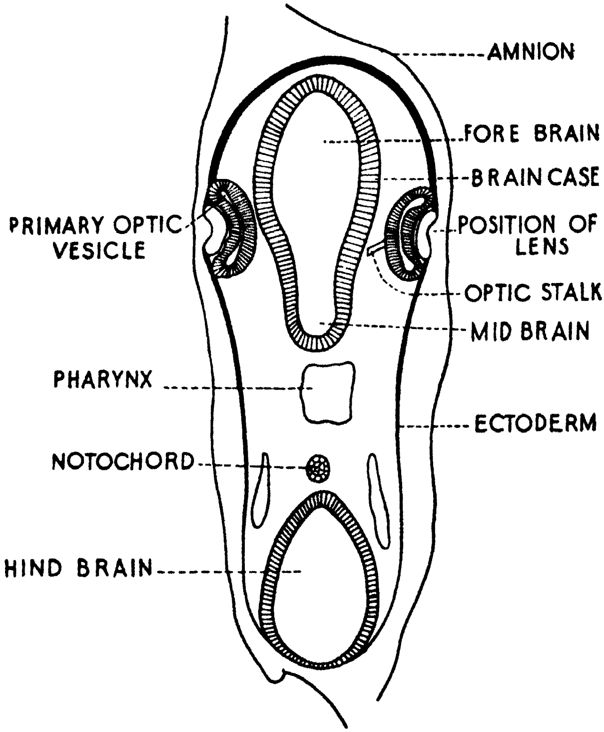


Fig. 240. Diagrammatic Section through Head of Chick (48 Hours).

the coelom a small outgrowth appears. These are the beginnings of the excretory system. About a dozen of these archinephric tubules develop on either side (Figs. 231 and 238), and their outer ends join together to form a duct which develops posteriorly and eventually opens into the

cloaca, cf. Fig. 227. Later these tubules are absorbed and the duct becomes the mesonephric duct. The mesonephros arises, from the cell mass between the somatic layers, as a series of tubules (Fig. 238), leading from the coelom. The mesonephros functions as a kidney during part of the chick's development, the waste products which collect in the allantois being lost when the chick hatches.

The **alimentary canal** arises in three parts, the stomodaeum, mesenteron, and proctodaeum. The first of these arises as an ingrowth of the epiblast on the third day (Fig. 239), and later joins with the fore-gut. The fore-gut is formed from the mesenteron as a pouch of the hypoblast and appears much earlier. Later a similar pouch forms the hind-gut. These two pouches deepen until only a narrow passage remains between the central part or mid-gut and the yolk sac. The proctodaeum is an ingrowth of the epiblast which joins the bend-gut and forms part of the cloaca.

As the time for hatching approaches, the very small yolk sac is drawn inside the body-wall. On the nineteenth or twentieth day the chick lies with its beak close to the air chamber in the egg. It bursts through its enveloping membrane and begins to breathe. It breaks the shell with a special tooth on its beak. The allantois dries up and on the twenty-first day the hatching is completed.

6. THE RABBIT

The ovum of the rabbit, a typical mammal, is about the same size as that of Amphioxus, and practically alecithal (Gk. *a* = without, *lecithal* = yolk). There is a yolk sac without any food material, and an amnion and allantois are formed very much as in chick. The embryo is retained in the egg, within the oviduct, until a stage of development corresponding with that at which the chick is hatched. Here the yolkless condition is not primitive but a secondary modification.

The ovum differs from the preceding types by the more complex character of the follicle. The cells from which ovum and follicle are developed are a specialised part of coelomic epithelium, known as the **germinal epithelium.** Small groups of cells, oogonia, giving rise to oocytes, sink into the underlying connective tissue, and soon an ovum is formed surrounded by a single layered follicle. In rabbit the follicle cells multiply, then a slit appears and grows into a large cavity filled with liquid. The vitelline membrane is thick, and marked with radiating lines, hence the term **zona radiata.** The ovum escapes from the follicle and enters the fallopian tube, where it is fertilised after giving off two polar bodies in the usual way.

The segmentation is holoblastic and nearly equal. When eight cells have been formed the segmentation cavity becomes filled by one of the cells passing into the centre. The three sister cells of this one tend to do the same, so that a solid mass of cells consisting of two layers is produced, known as the **morula.** The outer layer is not completed at one point, known as the pseudo-blastopore. The ovum being small the blastoderm quickly encircles the yolk area, and in the absence of the yolk the central part sinks into the hollow thus produced.

A space gradually develops between the two layers (Fig. 241), and becomes filled with fluid; the outer layer becomes thinner and more extensive until the inner layer becomes a little cap on one side of a hollow bladder. This cap is the blastoderm proper from which the embryo is formed. This and the later developments closely resemble stages of the chick development, the chief differences being in the extra-embryonic structures.

Because of the absence of yolk, when the ovum has entered the uterus the yolk-sac grows out towards the wall of the uterus, from which it is separated by the false amnion and follicle. The wall of the yolk-sac fuses with the portions of these membranes with which it comes in

contact forming a **false chorion** (Fig. 242). This unites closely with the wall of the uterus, forming an attachment called the temporary, or yolk, placenta. By this connection the embryo obtains food from its mother by diffusion.

When the allantois grows out, it too fuses with the outer

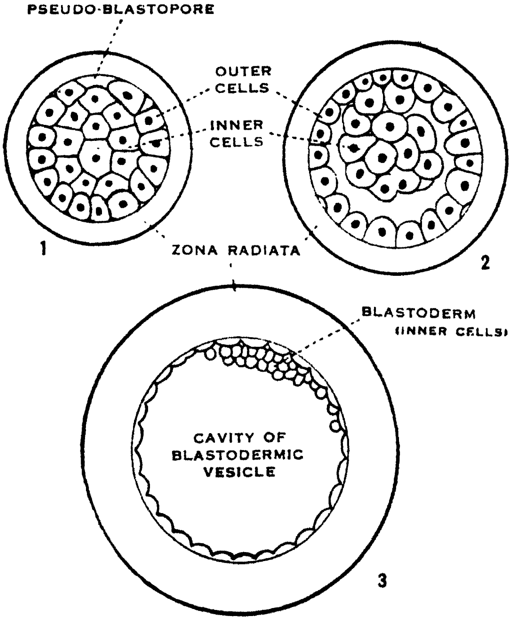


Fig. 241. RABBIT.
Segmentation of Ovum. (From Balfour, after Van Beneden.)

membranes, forming the **true chorion.** This forms a more permanent connection with the uterus, the **placenta.** From the true chorion, numerous projections grow out and become closely interlocked with others of the uterus wall, establishing a very close connection between parent and embryo, by which means the embryo is more adequately

fed; it is also protected until the time of birth. Before birth the body wall is incomplete ventrally where it is continuous with the amnion and where the stalks of the yolk-sac and allantois pass out. The scar of closure at this point persists as the **umbilicus**, or navel. The stalk of the allantois remains as the urinary bladder. The young rabbits are born in the true amnion.

In the consideration of the formation of the next generation, we see how, as we ascend in the scale of life,

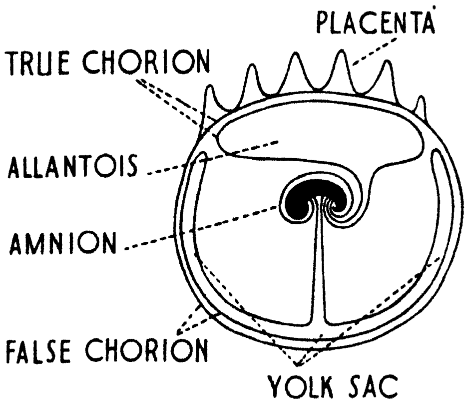


Fig. 242. RABBIT.
Extra Embryonic Structures. (After Balfour.)

the parent is no longer sacrificed to produce the offspring, as in Amoeba and bacteria. Gradually, too, the embryo is fed and protected by the parent longer and longer in its life, so that it becomes more able to fight for itself in the large world into which it finally emerges. In addition to considerations such as these, the study of embryology relates together in their early life and development, forms which may be vastly different superficially in their adult life, consequently it has proved of vast importance in connection with studies of evolution and heredity.

CHAPTER XVI

FERNS

1. INTRODUCTORY

The bracken fern (*Pteris aquilina*) is the well known fern of our moors and commons, which is so pleasing in the spring, when the young, delicate green leaves, usually spoken of as fronds, begin to push through the soil. It continues to please in the summer, when the large fronds, now three, four, or even five feet high, seem to provide a cool, refreshing atmosphere. In the autumn, they are again beautiful, when the green colour which has finished its work gradually becomes golden-brown, later giving place to the rusty brown of the ground.

When the **frond** first appears above the ground, it is rolled up in a characteristic manner (Fig. 243), known as circinnate. In this stage it resembles an eagle's foot, and this has given it the specific name aquilina (*aquila*, L. = eagle). The delicate tip of the frond is right in the centre of a spiral coil, the outside of which is the base of the leaf stalk. In this young, delicate condition, it lies beneath the surface of the ground during the winter and is protected by innumerable small brown scales. The stalk, which grows to be very long and strong, emerges from the soil and continues to the tip of the leaf; it is called a **rachis.** In the bracken fern the rachis is branched right and left, and these branches bear a very much branched, flat, green part, called the **lamina.**

2. THE RHIZOME

The fronds arise from a dark brown, cylindrical, branched subterranean stem, known as a **rhizome,** because it resem-

bles a root in position, living on from year to year, and making the fern a **perennial.** From the rhizome roots also arise, associated with the development of each frond; these make their way into the soil to obtain water and mineral salts in solution, and are thin and wiry and almost black in colour.

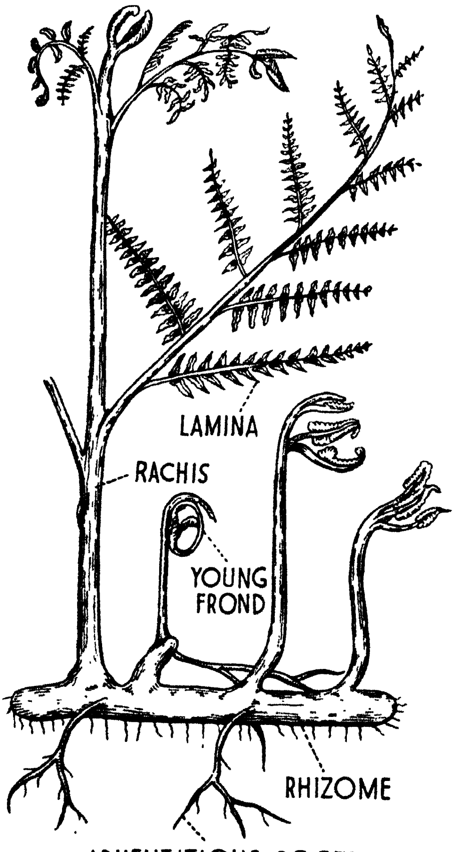


Fig. 243. BRACKEN FERN.

If the rhizome be cut across, the parts shown in Fig. 244 will be seen.

There is a protective outer layer, then some white tissue with a number of special areas enclosed in it. The white part is separated into an inner and outer part by a dark brown horseshoe of strengthening tissue. The latter is very efficient in preventing the rhizome from being easily crushed by the pressure of animals walking on the soil above it. The dotted area, known as the ground tissue, is very full of

starch, as can easily be discovered by applying a drop of iodine dissolved in potassium iodide, when the dark-blue colour will appear as it does when iodine is put on a piece of commercial starch. The other clear white areas constitute the conducting or **vascular tissue.** A fern is a much larger plant than any so far considered and, consequently, there is much greater division of labour and specialisation of cells. Water and mineral salts absorbed from the soil by the roots are carried into the rhizome, and thence into the fronds by a special system of cells known as the **xylem.** The xylem of trees is the tissue with which we are familiar in **wood.** The green fronds are the special organs for building up into nutriment the materials taken in by the plant; and, consequently, associated with the xylem, is another tissue, known as **phloem,** which is specially concerned with the distribution of food substances built up in the frond.

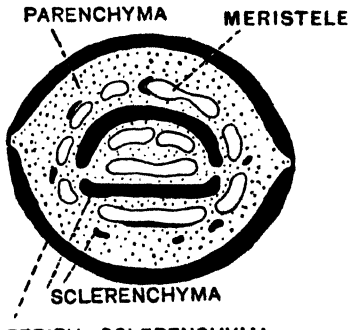


Fig. 244. PTERIS.
Diagrammatic transverse section of Rhizome.

A transverse section of the rhizome should be prepared for microscopical examination. The ground tissue will then be seen to be composed of large cells with thin cell walls. They contain protoplasm and a nucleus, as well as starch grains, and generally resemble the cells of the simpler plants that have been examined. The tissue they make is called **parenchyma.** In the outer layer, called the **epidermis,** the cells are much smaller, their walls a little thicker, and they usually contain a brown pigment. The cells making the horseshoe have very thick walls, and they are empty. Their walls are no

longer composed of cellulose, but of a firmer, harder, stronger substance, known as lignin, which was deposited on the inside of the original cellulose wall in the young cell. This change in the nature of the walls results in the protoplasm inside gradually being cut off from the supply of water and food, and it all being used in making the wall strong. This tissue is called **sclerenchyma.**

Each group of vascular tissue is called a **meristele.** The xylem occupies the centre of the group and is composed of cells, the walls of which have very straight edges and

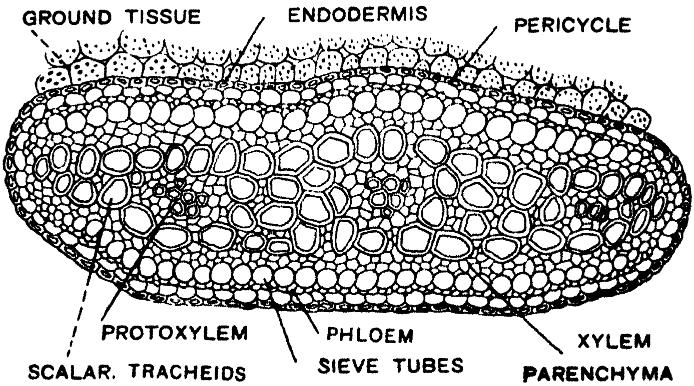


Fig. 245. PTERIS.
Transverse section of Meristele of the Rhizome.

fit very closely together (Fig. 245). They appear quite empty, since the sap they contain does not show. These cells, like all others, were once full of protoplasm, had large nuclei, grew into parenchyma cells which became long and thin, and later deposited lignin on their cell walls, eventually becoming empty tubes. These are known as **tracheids.** The first to be formed have the lignin deposited as a spiral band, and are much smaller in transverse area than those which develop later. They are known as **protoxylem.** The others have the lignin

deposited in a kind of ladder-like arrangement, so that they are called scalariform tracheids. To see the form of the lignin, longitudinal sections must be cut (Fig. 246).

Immediately outside and surrounding the xylem are some small, thin-walled cells. These are called **phloem.** They retain the general characters of parenchyma cells, but they are long and narrow, and they have some

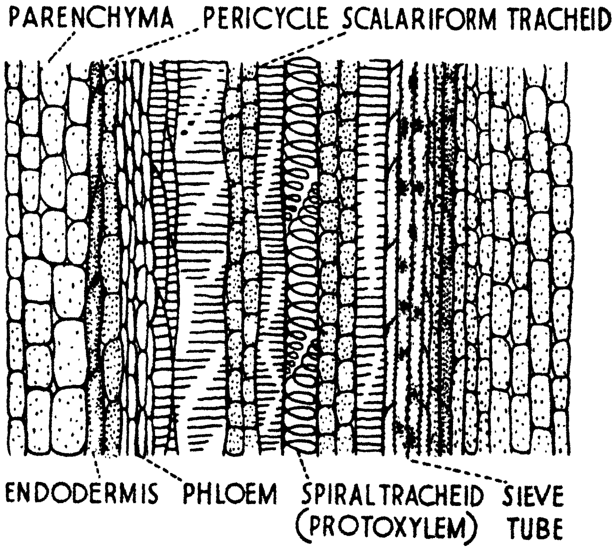


Fig. 246. Fern.

Longitudinal section through a Meristele.

perforated areas on their longitudinal walls, whence they get the name sieve tubes. In both the xylem and phloem, some cells remain at the parenchyma stage. Outside the phloem is a layer of parenchyma cells, known as the **pericycle.**

Outside these again is a distinctive layer with thicker, darkly-coloured cell walls, the **endodermis.** From certain

unthickened cells in this layer the roots develop. The growing point of the fern rhizome consists of an **apical cell,** which has the form of a three-sided pyramid. Cells are cut off parallel with these three sides to make the tissues of the stem, so that it is spoken of as a three-sided apical cell.

The fern **root** has an apical cell at the tip (Fig. 247) similar to that at the stem tip. Here division also occurs parallel with the external surface forming cells which make the **root-cap.** The root-cap is comparable with a thimble,

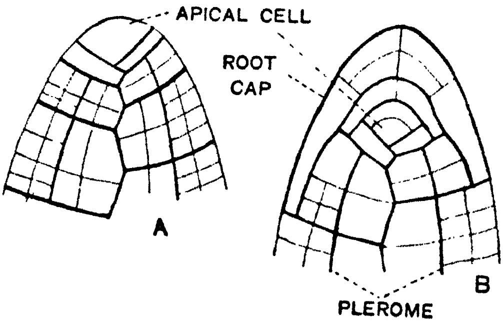


Fig. 247. FERN.

Diagrammatic longitudinal sections of apex of Rhizome and Root. A, Rhizome; B, Root.

it is a covering over the very important delicate growing cell of the root, so that this is not damaged while it pushes its way into the soil. Near the tip of the root, the cells are all soft and delicate. Those from which the vascular tissue will develop are called plerome. They are parenchyma cells; and a little way behind the tip some of the surface cells grow out and make long, thin parenchyma cells, known as **root hairs,** which make their way between soil particles. They help to maintain a firm hold in the soil, they provide a large surface area, and are the organs which absorb water and mineral salts from the soil for the fern.

Further back the root becomes very firm. In the centre is a small group of vascular elements (Fig. 248).

The xylem is central because it is strong, and in this

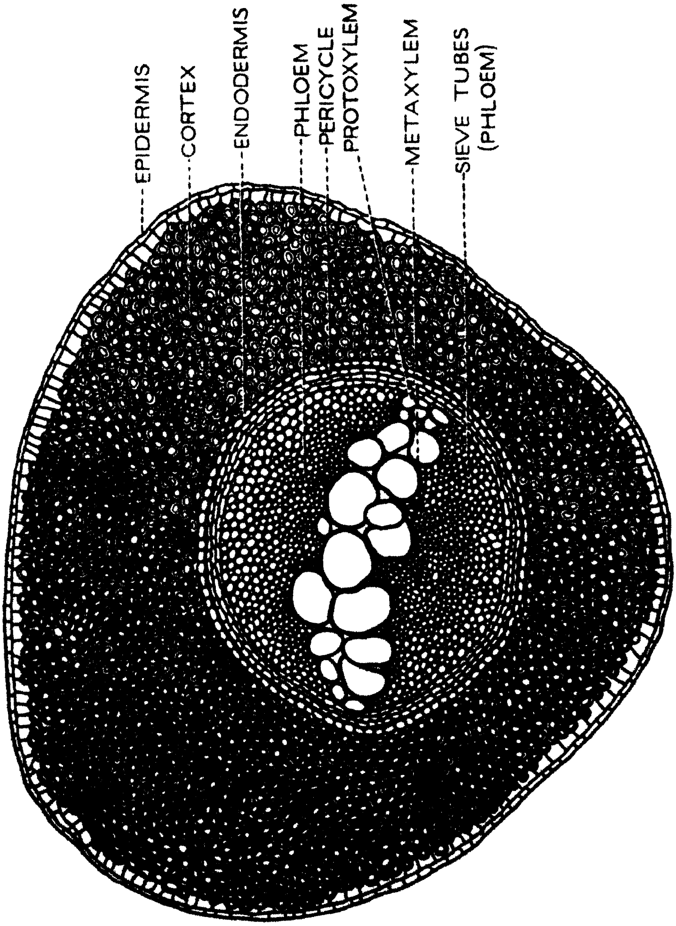


Fig. 248. Pteris Aquilina. Transverse section of Root.

position helps to give the root the strength needed to resist pulling strains. There are two groups of

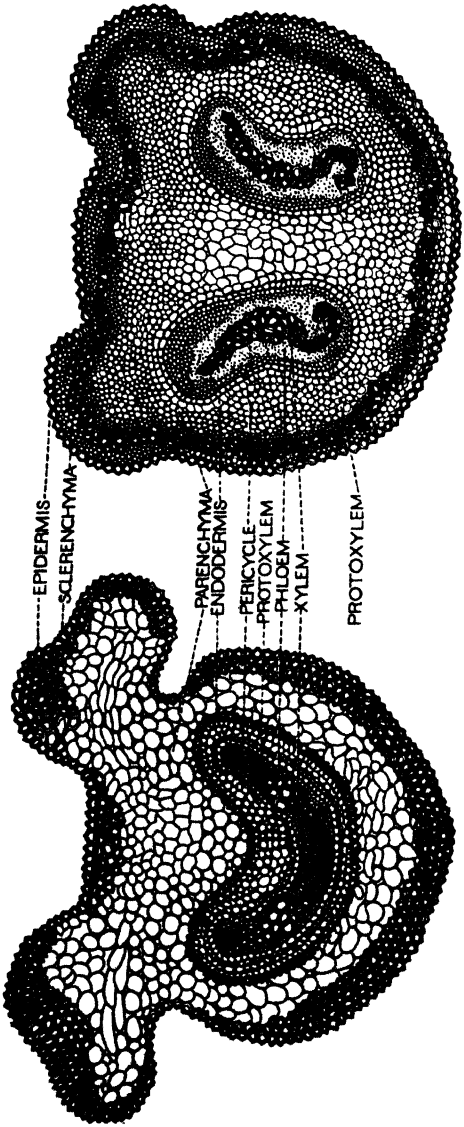


Fig. 249. Transverse Sections of Rachis of Pteris.

protoxylem at the edge of the xylem. The rest of the xylem is spoken of as metaxylem. It arises from the growing point, but develops a little later than the protoxylem. The phloem does not go all round the wood, but occurs in two groups in the positions which alternate with the protoxylem. Around the xylem and phloem is the pericycle; and next to that the firmer dark-coloured endodermis. Between the endodermis and the epidermis, the tissue is called **cortex.** There are a few parenchyma cells next to the endodermis, but most of the cortex is sclerenchyma,

giving the root its dark colour and the wiriness associated with fern roots.

3. THE RACHIS

Examination of the rachis shows a groove on the upper side, which serves to collect rain and direct it to the soil at the base of the frond where its root will occur. A transverse section of a rachis shows two meristeles,

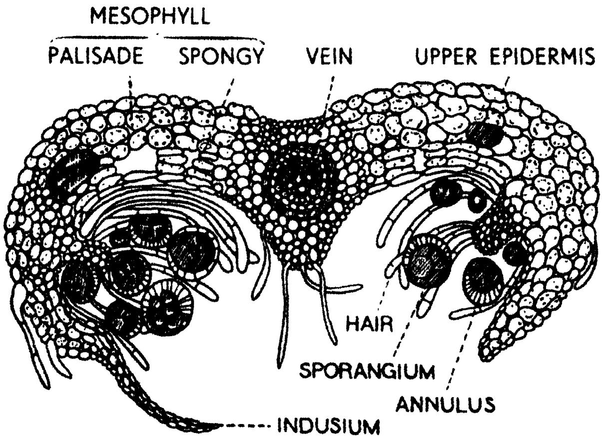


Fig. 250. PTERIS.

Transverse section of leaf with Sporangia.

which, in some parts, are joined to form a crescent round the under side of the rachis, leaving the gap opposite the groove on the upper side (Fig. 249).

There is a well-defined protective epidermis and concentric layers of sclerenchyma within it. Here a different kind of strength is needed. The frond is blown about by the wind and therefore needs to be elastic and flexible. The rachis also has to support the weight of the flat green part, or lamina, of the frond.

4. THE LAMINA

The upper surface, which receives the sun's rays, is a darker green colour than the lower surface, which is in the shade. The margin of the leaf is rolled under slightly to enclose a number of minute brown bodies. These are the sporangia.

A transverse section of the leaf (Fig. 250) shows a distinct layer of cells on both surfaces; these are the upper **epidermis** and the lower epidermis. Beneath the upper epidermis the cells are very regularly placed and rather compact, those nearer the lower epidermis are arranged to enclose a large number of air spaces. These cells all compose the **mesophyll**, or middle tissue of the leaf. The upper are called the **palisade mesophyll**, and their chief work is food building. The lower tissue is the **spongy mesophyll**, and its chief work is to collect materials for food building, and also waste products.

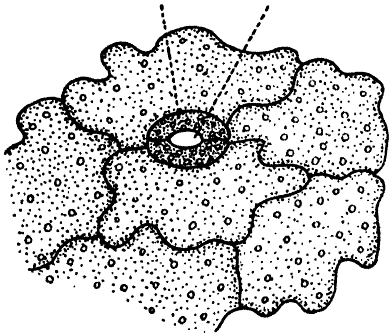


Fig. 251. FERN.
Cells of lower epidermis of Leaf.

In the lower epidermis can be seen pairs of special small cells which have a small opening, or pore, between them. The two cells are called **guard cells**, because they are able to regulate the size of the pore, which is called the **stoma.** A piece of the lower epidermis should be stripped off and mounted to see the stomata (Fig. 251). The guard cells will then be seen to be sausage-shaped in surface view. While they are full of sap, and therefore

distended, the pore is open. Draw a little salt solution under the cover slip, by placing a drop on the slide at one side of it and applying a piece of blotting-paper at the opposite edge. If the solution is strong enough it will draw water from the guard cells and their walls will

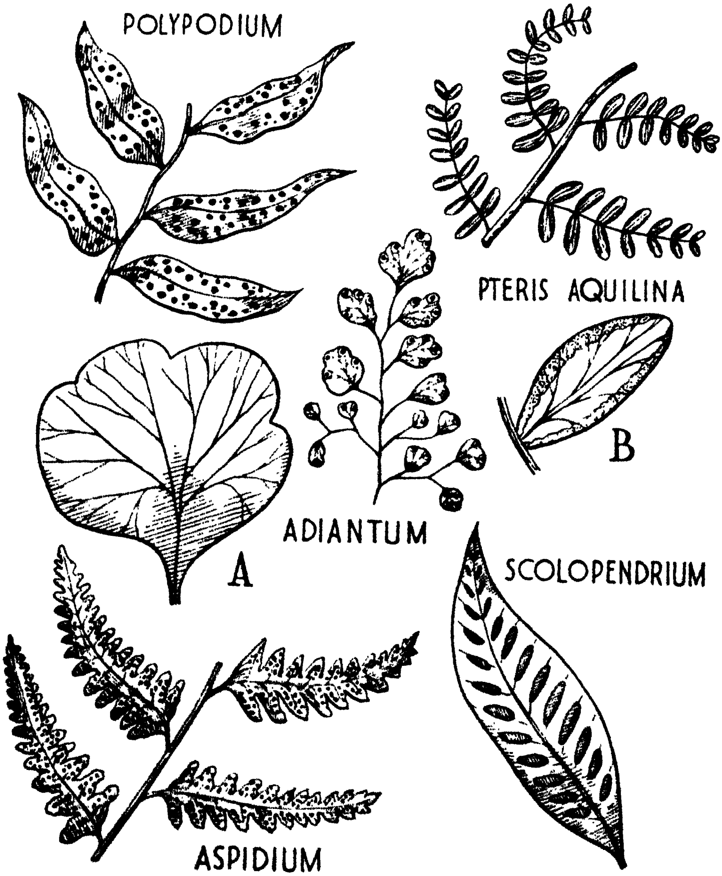


Fig. 252. FERN FRONDS.
A, Adiantum enlarged to show veining; B, Pteris aquilina enlarged.

lie limply side by side, thus closing the pore. This is of great assistance to the plant, because if conditions are dry and the leaf cells are not getting an abundant supply of water, the stomata will be closed, and it will be more difficult for water vapour to escape from the surface of the leaf than when the pore is open. The epidermal cells will be seen to have a very wavy outline; this is characteristic of ferns, as is also the fact that they all have oval, disc-shaped chlorophyll grains within them.

This latter character is an adaptation to a somewhat shady situation. Ferns often form part of the undergrowth in a wood, where, when the trees are in full leaf, the situation will be rather shady. Ferns are usually the middle layer of vegetation, as it were, between the tall trees and smaller flowering plants, such as grass, which frequently are found with them. Above the soil their main growth occurs at different times of the year; this helps them to share the sunshine. Beneath the soil the rhizome and roots of the fern still occupy the intermediate position, the smaller plants having more shallow rooting parts, while the tree roots penetrate much deeper. In this way there is food and water enough for them all in the different layers of soil, and they live together quite happily, forming a community.

5. THE SPORANGIA

The brown material mentioned on the margin of the frond is seen in the transverse section (Fig. 250). The margin of the leaf is rolled over slightly, forming a false **indusium**, to protect the **sporangia** which grow there. It is characteristic of the genus Pteris that the sporangia grow along the margin, thus the common ribbon fern is Pteris. Other ferns carry their sporangia in different positions on the under surface, *e.g.* Maidenhair, *Adiantum*, has them on the edge, but in groups, known as **sori** (Fig. 252). This fern also shows specially well the arrangement

of the veins which is characteristic of ferns and spoken of as furcate. In the male shield fern, *Aspidium*, so commonly grown in gardens, there are two rows of sori, and each has a special somewhat kidney-shaped protective growth, the indusium. In Hart's Tongue, *Scolopendrium*, they are also in two rows, but long and fairly narrow. In *Polypodium* they are circular, and scattered all over the back of the lamina.

The sporangia arise from an epidermal cell, which divides to make a stalk cell, and the cell which forms the spore case (Fig. 253, A). The latter cell divides to make cells to form the wall, and one, the archesporium, which gives rise to a group of spore mother cells, after another layer has been cut off parallel with the wall to make the **tapetum**. The latter is specially concerned with feeding and developing spores. Each spore mother cell by reduction division produces four spores.

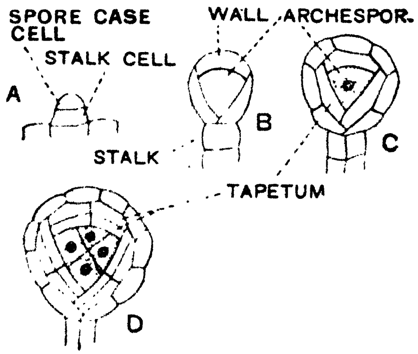


Fig. 253. FERN.
Development of the Sporangium.

While the spores are developing a special band of cells is formed in the wall of the sporangium. This band is just one cell wide; it begins at the stalk, and passes over the top of the case, but does not reach to the stalk on the other side. It becomes brown in colour, consisting of cells with the walls on three of their sides thick and strong, the outer wall remaining thin. It is known as the **annulus** (Fig. 254). When the spores are ripe, and the annulus cells give up their moisture on a dry, windy day, the outer thin wall

contracts, and this causes the thin cells between its end and the stalk to give way suddenly, so that the sporangia really open explosively and are turned inside out (Fig. 254). This sends the spores out into the world with a little force to scatter them until the wind can pick them up and carry them further in search of a new home.

6. THE GAMETOPHYTE

Each spore consists of a nucleus, cytoplasm, containing a little store of food, a delicate inner cell wall, and a thick outer protective coat. It rests through the winter and begins to grow in the spring. The spore absorbs water, the outer coat is burst, and a rhizoid is developed, which pushes its way into the soil. A thin, delicate, green thread is next produced along the surface of the ground, and this very soon produces an apical cell, which develops into a flat, green, heart-shaped thallus (Fig. 255). This growth reminds us of Pellia and, as in Pellia, the fern spore has developed a small **protonema,** from which grows a **gametophyte,** often spoken of as the prothallus.

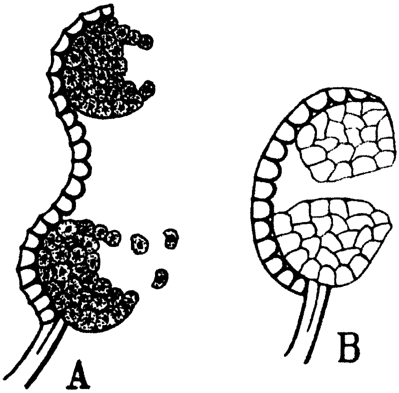


Fig. 254. FERN SPORANGIA.
A, the annulus curled right back; B, the annulus recoiled and spores ejected.

The gametophyte remains quite small, only growing to be about half-an-inch across. It is only one cell deep, except in the centre; it can thus be mounted whole for microscopic examination. From the central cushion numerous unicellular rhizoids develop. The thallus grows

from a two-sided apical cell. It is green and quite an independent little plant. After a time the apical cell cuts

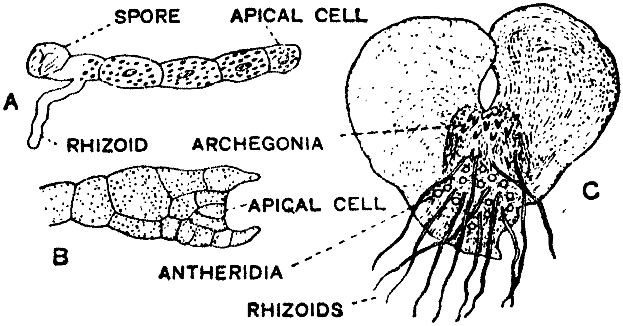


Fig. 255. Fern.
Germination of Spore and Development of Prothallus.

off some cells, each of which is destined to become an **antheridium** (Fig. 256). This resembles the antheridium of Pellia, but is rather smaller. The antherozoids are characterised by having a tuft of cilia, instead of only two. After several antheridia have been formed, the apical cell produces other special cells which develop into **archegonia** (Fig. 257). These again resemble those of Pellia, but their

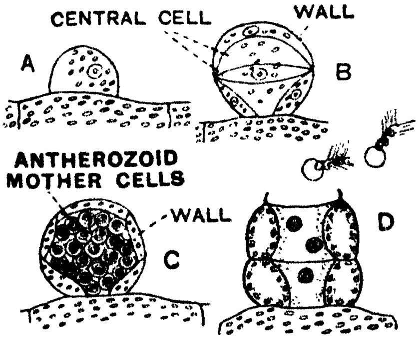


Fig. 256. Fern.
Development of Antheridium.

necks are shorter, and because the oosphere is buried in the thallus, there are no cells forming the venter. When the oosphere is ready for fertilisation the neck canal cells

become mucilaginous and some mucilage containing malic acid, which serves to attract the antherozoid, exudes from the neck of the archegonium. During wet weather the antheridia burst and free the antherozoids, which then swim to the archegonia. Fusion of the male and female gametes results in an **oospore.**

The oospore divides by a division which is longitudinal to the archegonium and so placed that one cell faces the

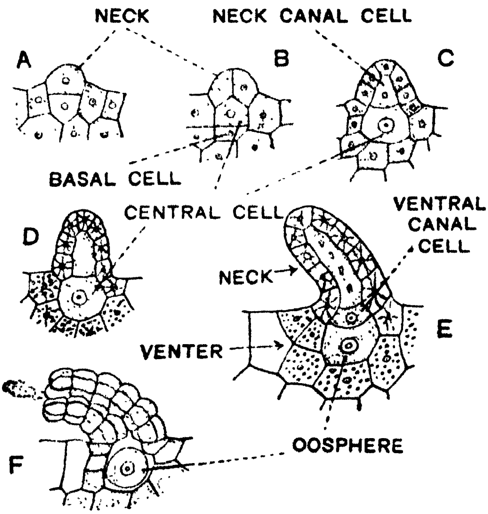
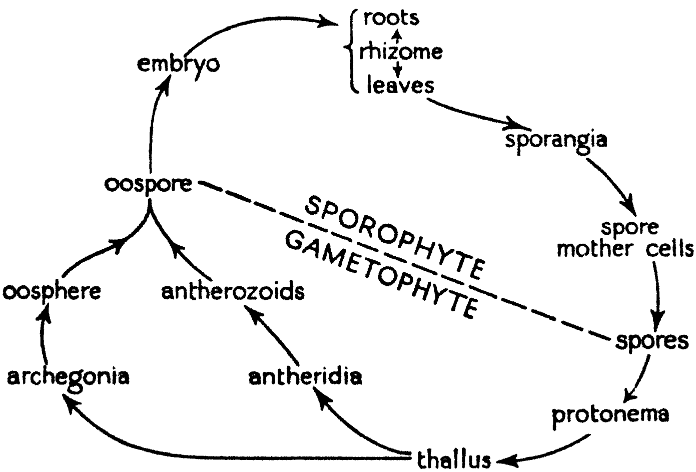


Fig. 257. FERN.
Development of Archegonium.

apical cell of the gametophyte. This cell is known as the epibasal cell, while the other one is the hypobasal cell. A second division occurs at right angles to the first, and then another one at right angles to them both, that is in the plane of the paper in Fig. 258. Thus eight cells, known as octants, are produced from the oospore. Two of the hypobasal cells develop into the foot; one forms the young root, and the fourth develops no further. One of the

epibasal cells makes the young stem, two the first leaf, and the fourth develops no more. Thus is formed an embryo fern plant like the one with which we began (Fig. 259). In the case of Liverworts and Mosses, the oospore produces a sporophyte which is entirely, or at least to a very considerable extent, parasitic, on the gametophyte. Here in the fern the sporophyte in its early life is parasitic on the gametophyte; but later it becomes independent, forming the rhizome, roots, and fronds with which we are familiar. It will have been noticed that although this generation is large and perennial, it is the spore producing part. The life cycle of a fern may be written:—



7. THE SPOROPHYTE

It will be seen that there is considerable agreement between this and the life cycle of Pellia. The difference is brought about by the fern having become more adapted to the land habit. The gametes still need water so that they may come together; consequently the gametophyte has not become specialised, but the sporophyte has acquired a

new independence. In the mosses the sporophyte had developed some green tissue not engaged in spore production. In the fern the sporophyte has not only become independent, but developed to be much the larger, more obvious part of the plant. Being a new structure, it was able to specialise to meet the needs of the environment. Thus the vascular tissue is quite a new development.

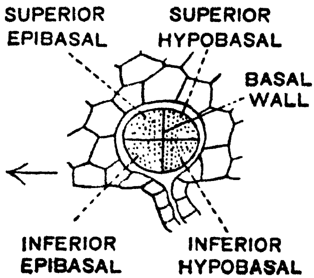


Fig. 258. FERN.
Segmentation of the Oospore. The arrow points anteriorly. (Diagrammatic.)

The embryo sporophyte develops very slowly and it takes a considerable number of years before the large plant with which we started has grown. It quite soon, however, becomes independent of the gametophyte. The leaves at first are very small and it is some years before they produce sporangia. When the vascular tissue develops in the young sporophyte, it is one solid rod of

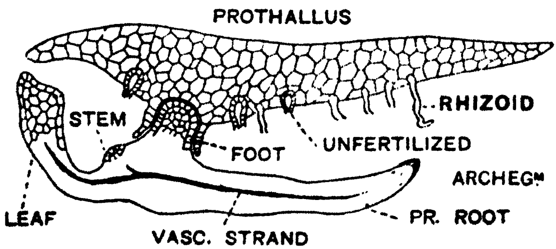


Fig. 259. FERN.
Embryo attached to Prothallus. (Longitudinal section.)

xylem, surrounded by phloem, outside which is the pericycle, then endodermis. This is called a **protostele**, that is, the first formed stele, and in the rachis the stele, spoken of as the leaf trace, is similar (Fig. 260). Later, as both

stem and leaf get larger, the vascular tissue expands, so that the xylem becomes a hollow cylinder. Then gradually there develop phloem, pericycle, and endodermis on the inner side, with a little ground tissue in the centre.

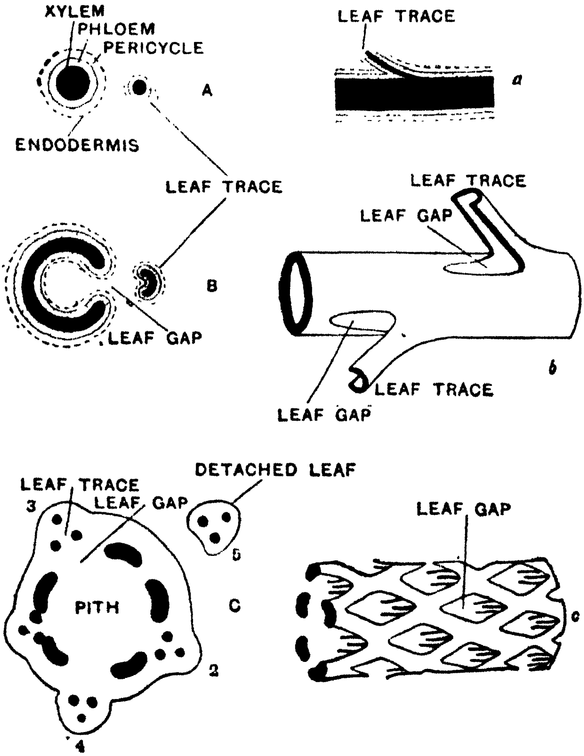


Fig. 260. FERN.
Diagrams to illustrate types of Vascular System. A, a, Protostele; B, b, Solenostele; C, c, Dictyostele.

This is called a **solenostele,** and the rachis has a crescent-shaped stele (Fig. 260, B). Later, as more leaves are produced and they occur close together on the rhizome, the gaps in the vascular tissue, where the crescent

of the rachis and the cylinder of the rhizome join, are always present. Thus the cylinder ceases to be continuous, but becomes a number of parts, which are called meristeles. The whole stele is a **dictyostele** (Fig. 260, c). As this development proceeds, the rachis may also come to contain a dictyostelic arrangement, but the meristeles are always placed so that they would form a crescent round the ventral side. If the vascular tissue were dissected out from a piece of rhizome, it would have the form of lattice-work (Fig. 260, c). In bracken, as the leaves become very large, the amount of vascular tissue is increased by the infolding of the dictyostele to form the central meristeles. Thus as the sporophyte increases in size, so its structure becomes more complex to supply the ever-increasing needs.

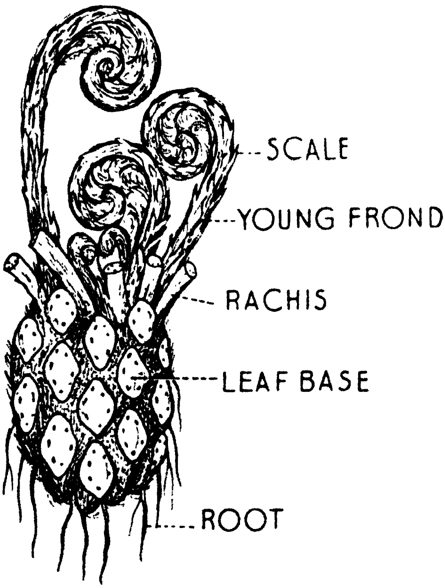


Fig. 261. Rhizome of Aspidium.

8. THE MALE SHIELD FERN

The fern commonly grown in gardens is the male shield fern, *Aspidium* (*Dryopteris*) (*Lastrea*) *Filix-mas*. It differs from bracken in that it has a short, erect **rhizome** (Fig. 261) from which a circle of fronds arises each year. The rhizome is closely covered with leaf bases.

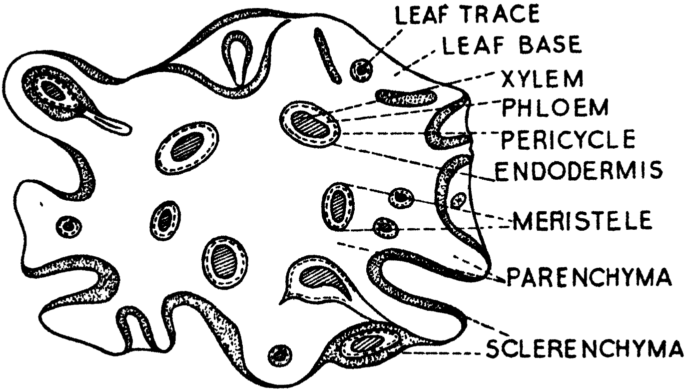


Fig. 262. Plan of Transverse Section of Rhizome of Aspidium Filix-mas.

A transverse section of the rhizome shows a circle of meristeles, which constitute a dictyostele (Fig. 262). There is a large central area of parenchyma cells containing starch grains. Sclerenchyma is only present immediately beneath the epidermis and often there is very little present.

In the **rachis** it is usual to find a number of meristeles. These are arranged in the form of a crescent, placed so that the open end faces the centre of the plant (Fig. 263). The side of the rachis facing the centre of the plant is flat and somewhat grooved, so that the rain may be directed to the roots at the base of the frond.

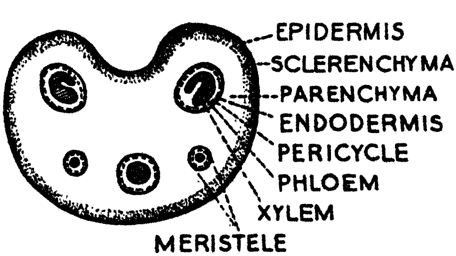


Fig. 263. Plan of Transverse Section of Rachis of Aspidium Filix-mas.

The frond of this fern is much less branched than that of bracken, and the **sori** are

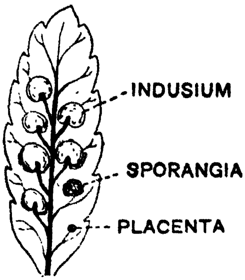


Fig. 264. Pinnule of Aspidium bearing Sori.
The indusium has been removed from one placenta, the indusium and sporangia from another.

arranged in two rows on the underside of each small piece of the lamina (Fig. 264). The sporangia develop all round a placenta, from which a kidney-shaped protective covering, called an indusium, grows over the sporangia (Fig. 265).

The remaining parts of this fern resemble those of bracken and the same characteristic **alternation of generations** occurs. The well-known sporophyte is followed by the less familiar, but equally independent, gametophyte. The nuclei of the sporophyte possess the double number of choromosomes, while those of the gametophyte have the reduced number. The enormous number of asexual spores produced by the sporophyte provides the possibility of a large number of gametophytes. The latter generation is concerned with sexual reproduction and the benefits which result from it.

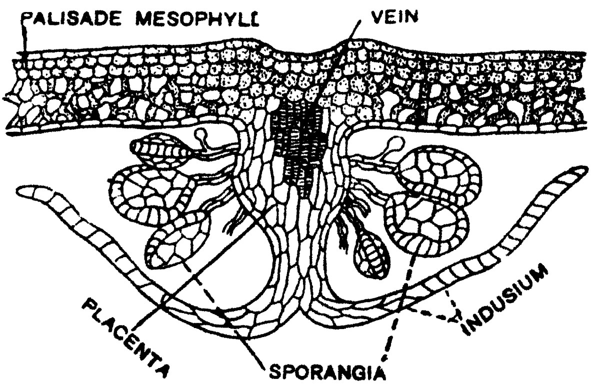


Fig. 265. Sporangia of Aspidium.
(Transverse section through a pinnule and sorus.)

CHAPTER XVII

A PINE TREE

1. INTRODUCTORY

Conspicuous amongst trees during winter are those belonging to a class of plants, which produce cones and have evergreen foliage, such as the common pines or firs. The familiar Christmas tree (*Picea excelsa*) is a fir tree, and Scots Pine (*Pinus Sylvestris*) is a well known pine. Both these types have needle-shaped foliage leaves, which arise singly in firs and in groups in pines.

2. EXTERNAL CHARACTERS OF SCOTS PINE

Scots Pine trees are often very tall with only the upper branches persisting (Fig. 266). The trunk is covered with rough, scaly bark, and two or three branches often arise at the same level. The evergreen foliage leaves are long and needle-shaped. They occur in pairs in *Pinus sylvestris*, but the number varies according to the species. These leaves are borne on **dwarf shoots,**

Malby

Fig. 266. SCOTS PINES.

that is, very short stems which arise in the axils of very small membranous scale leaves, and bear only the characteristic number of foliage leaves (Fig. 267). The dwarf shoots occur very close together. When eventually leaves are shed, the whole dwarf shoot falls off and leaves the branches very rough in appearance.

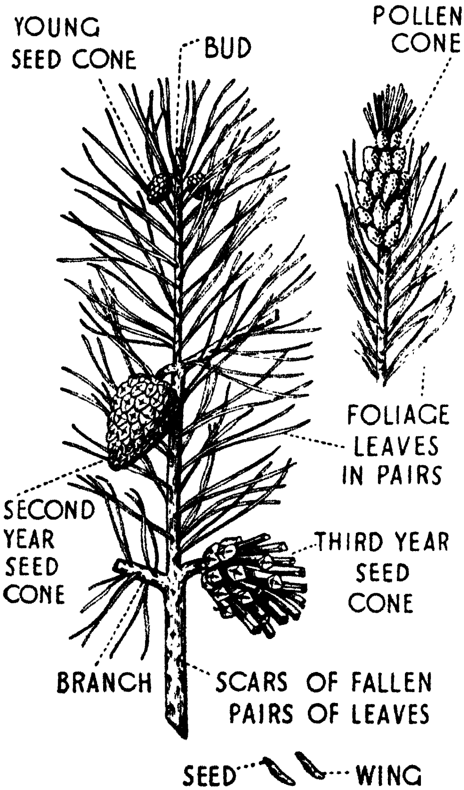


Fig. 267. Branch of Scots Pine (*Pinus Sylvestris*).

A long branch ends in a terminal bud, and immediately below this in the autumn there are other buds or young seed cones (Fig. 267). Usually three are present at the same level. They may be all lateral buds, or all cones, or a mixture of the two. The buds are covered with brown, membranous scale leaves and will give rise to long branches bearing dwarf shoots. The cones after two or more seasons of development will contain seeds ready for dispersal. If branches are examined in May, when the buds are developing, in some cases groups of pollen cones

will have appeared before any new dwarf shoots. The pollen cones arise on the branch in the same positions as dwarf shoots (Fig. 267). Pollen cones are therefore said to be **homologous** with dwarf shoots. Seed cones are homologous with lateral branches.

The main root may be very long or it may be short according to the situation in which the tree is growing. In either case many lateral roots will spread out over an area of soil approximately equal to that below the largest branches.

3. ANATOMY OF THE STEM

A transverse section of a long branch very near its tip

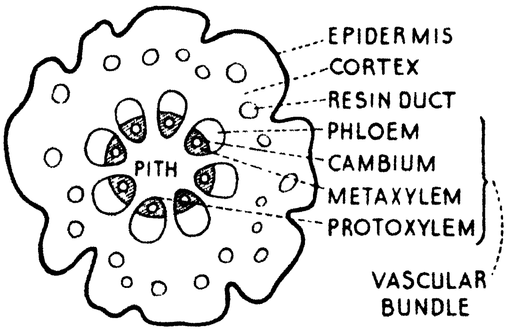


Fig. 268. Transverse Section of Young Stem of Pinus Sylvestris.

shows the structure of the young stem It will be found to have an **epidermis, cortex,** and a ring of oval-shaped masses of vascular tissue surrounding some parenchyma cells known as the **pith** (Fig. 268). The xylem elements are nearest the pith and are separated from the phloem elements by a band of meristematic cells known as the cambium. These oval groups of vascular tissue are spoken of as **vascular bundles.** They are separated from one another by a narrow strip of parenchyma, which joins the cortex and pith, and is called a **medullary ray** (medulla = pith).

In the cortex and xylem of Pinus there are **resin-ducts.** These are passages surrounded by a layer of glandular, epithelial cells, which secrete resin and thus make the duct (Fig. 268).

In a transverse section of an older stem the **cambium** is a continuous ring, and there is a good deal of xylem on its inner side (Fig. 269). This additional xylem, between the cambium and the somewhat wedge-shaped masses of

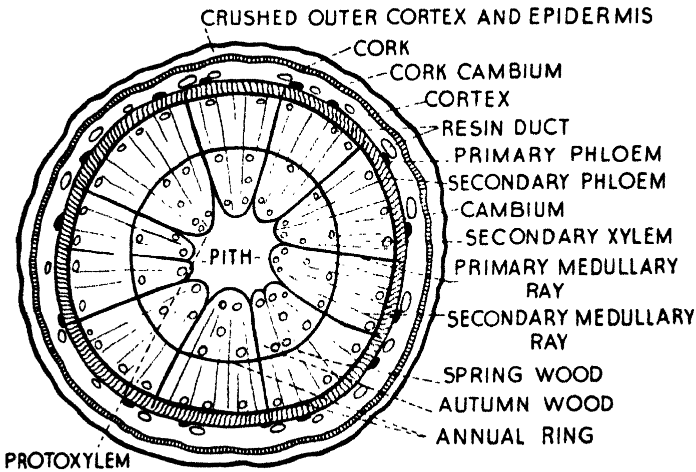


Fig. 269. Transverse Section of Stem of Pinus with Two Years of Secondary Growth.

primary xylem, is spoken of as **secondary xylem.** It has been formed by the cambium. The cells of the cambium divide so that each becomes two. Of these two cells one remains a cambium cell and the other divides to make two cells of permanent tissue. If they are on the inner side of the cambium they become two secondary xylem cells. If the new cells are outside the new cambium cell they become **secondary phloem** which forms a band outside the cambium, between it and the somewhat isolated patches of primary

phloem (Fig. 269). The primary medullary rays can be traced from the pith to the cortex and there will be many more in the secondary xylem, known as **secondary medullary rays.** This addition of new tissues causes an increase in

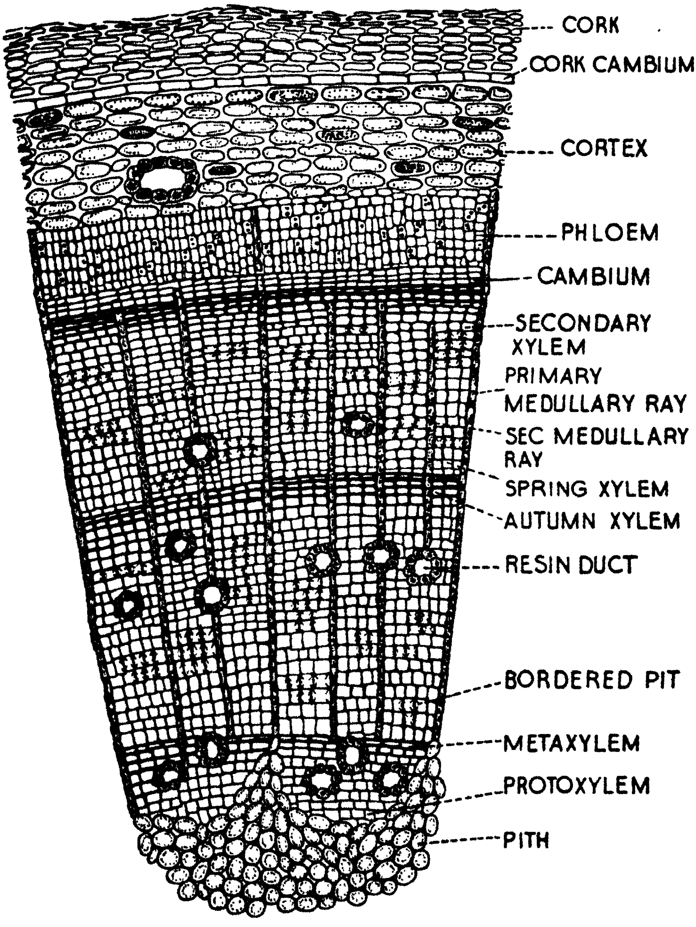


Fig. 270. Part of Transverse Section of Stem of Pinus showing some Secondary Growth.

girth, so that the branches and tree trunk get thicker each year.

The increase in the circumference necessitates the formation of new tissue on the outside as the original epidermis becomes inefficient. For this purpose a layer of meristematic cells arises towards the outside of the cortex, called the **cork cambium** (Fig. 269). From this layer **cork** is formed on the outside and some additional cortical cells on the inside.

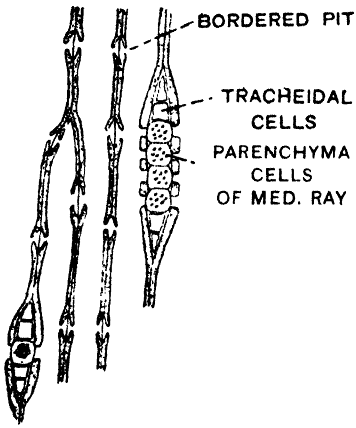


Fig. 271. Secondary Wood of *Pinus*.
Portion of a tangential longitudinal section.

The age of the stem can be determined from the xylem, because a ring of secondary xylem is added each year. This is apparent because each year a new ring of resin ducts is formed amongst the **tracheids**, and also because the tracheids formed in the spring are larger and have thinner walls than those formed the previous autumn (Fig. 270). Spring is the season of renewed activity, and large tracheids are produced quickly to meet the increased demand made by the foliage for sap.

Close inspection of the tracheids will reveal in some cases a characteristic deposition of lignin on the radial walls (Fig. 270). Longitudinal sections are needed to discover more about the structure of the vascular tissue. If they are cut along a radius of the stem they are spoken of as longitudinal radial sections. If they are cut only a short distance in the wood they are spoken of as longitudinal tangential sections. In the longitudinal tangential section

the lignin appears to be arranged as in the transverse. The continuous cellulose membrane can be seen, on which lignin is deposited evenly for some distance and then curves into the tracheid (Fig. 271). Then follows a space in the lignin, a pit, beyond which the lignin curves back to cellulose membrane. On the cellulose immediately opposite the pit is a deposit of suberin, the torus. In the longitudinal radial section on the surface of the tracheid

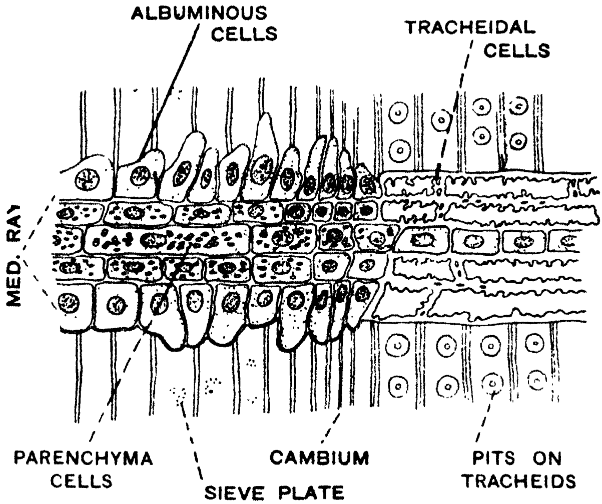


Fig. 272. Radial Longitudinal Section of Stem of *Pinus*. The section is taken at the junction of secondary wood and phloem.

wall can be seen a row of two concentric circles (Fig. 272). The small circle is the pit and the other the edge of the raised lignin. This is characteristic of the wood of *Pinus* and plants allied to it, and is called a **bordered pit.** Where two tracheids lie side by side the bordered pits are placed together as in Fig. 273. Sap passes from one tracheid to another through the pits and the cellulose wall beneath the border. The torus just fits into the pit, if for any reason

the pressure becomes sufficiently great on one side of the cellulose membrane to stretch it that far, and prevents the cellulose stretching beyond this point and breaking.

If the longitudinal radial section passes through the first formed tracheids of the primary xylem, that is, through the **protoxylem,** these tracheids can be distinguished because their lignin is deposited in a spiral. The structure of the protoxylem therefore agrees with that of a fern; but the structure of the rest of the xylem is characteristic of cone bearing plants. The phloem also resembles that of ferns, as it consists of **sieve tubes** with small sieve plates on their longitudinal walls. As the sieve plates are present only on the radial walls, they are only apparent in the longitudinal radial section (Fig. 272).

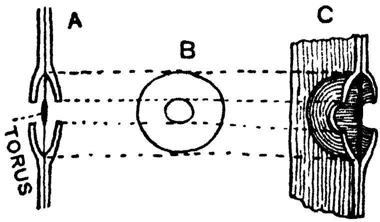


Fig. 273. The Bordered Pit.
A, Longitudinal section; B, Surface view; C, Semi-profile.

Conspicuous in the longitudinal sections are the **medullary rays.** These are plates of cells placed radially either in the secondary xylem or extending from pith to cortex. In the longitudinal radial section the plate of cells is apparent (Fig. 272). In the longitudinal tangential section the medullary rays are essentially a row of cells (Fig. 271); they may in places be more than one cell wide. The length of the row of cells varies.

In the transverse section they have been noticed, and here again they are essentially one cell wide. The longitudinal sections show that although the majority of cells in the medullary rays are parenchyma, the cells at the top and bottom of the ray are different. In the xylem area these cells appear empty, because they are slightly lignified and they have bordered pits on their walls; they

are called tracheidal cells, and help with the work of the tracheids. The primary rays extend into the phloem, and here the top and bottom cells are somewhat elongated and very full of contents; they are called albuminous cells and assist the phloem. Medullary rays contain the food stored in the tree, for the winter and renewed activity in the spring.

4. ANATOMY OF THE ROOT

In the transverse section of a young main root there are two groups of protoxylem elements and two groups of phloem surrounded by **pericycle** and **endodermis.** Outside this is a wide cortex of parenchyma cells and the epidermal layer. This is very similar to a fern root, but it is readily distinguished because in the pericycle immediately outside each protoxylem group is a resin duct (Fig. 274). A pine tree has a main root and from its pericycle outside the protoxylem groups lateral roots arise, and these in their turn bear other roots in a similar manner. The lateral roots may have three or four protoxylems.

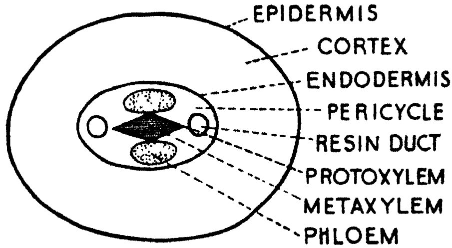


Fig. 274. Transverse Section of Young Root of Pinus.

The tip of the root is protected by a **root-cap,** and a short distance behind this **root-hairs** are produced from the surface cells. The root-hairs, however, are not usually so well developed as in many plants. When carefully examined along some distance from the tip the surface of the root can be seen to be clothed with some delicate hyphae of a fungus. These hyphae penetrate into the surface cells of the root with which they live in symbiosis.

The root provides the fungus with carbohydrate food material, while the fungus has greater power of obtaining material from the soil than root-hairs, because it can secrete enzymes to render more materials soluble and therefore available to plant life. A fungus associated with the roots of a plant in this way is called a **mycorhiza.**

As the root grows older cambium appears between the metaxylem and primary phloem. This forms secondary xylem on its inner, and a little secondary phloem on its outer side. This takes place for a time before the cambium becomes a continuous band passing outside the primary resin ducts (Fig. 275). It is the pericycle cells in this area which become active and join the primary strips of cambium together. From this time secondary growth continues as in the stem. The primary medullary rays are formed along the radii passing through the protoxylem and primary resin duct. Secondary medullary rays are formed in the secondary xylem. There is much less difference between the autumn and spring wood than in the stem, so that the annual rings are not very apparent.

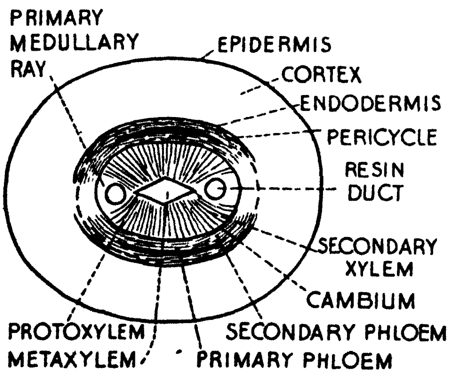


Fig. 275. Transverse Section of Root of Pinus with a Little Secondary Growth.

After secondary growth has gone on for some time, cork cambium develops from the outer pericycle layer. When the first cork has been produced the endodermis, cortex, and epidermal layer are cut off from their supply of water and food, so that they dry and help to make the first bark.

5. THE GROWING POINTS OF THE STEM AND ROOT

In the fern there is one apical cell at the tip of each organ from the divisions of which the requisite cells have their origin. In a pine tree there are many cells at the tips of the root and stem engaged in cell division, thus making a meristematic tissue. In a longitudinal section of a stem the ones in the centre which form the vascular tissue can be distinguished from the group which give rise to the cortex and epidermis. The lateral organs on the stem arise from the outer layers of the meristematic cells only, and are said to be exogenous.

At the root tip the central group can again be distinguished, also the group of cells which form the cortex. A third group of cells gives rise to the epidermis and root-cap.

6. THE FOLIAGE LEAVES

In *Pinus sylvestris* a transverse section of a foliage leaf is nearly semi-circular. Two needle leaves grow with their straight sides placed together on a dwarf shoot. These are evergreen leaves, and it is important that water vapour does not leave their surface too readily. The **epidermal cells** are small and covered with a thick **cuticle.** This is a secretion which helps rain and snow to slip off the surface easily and does not readily allow materials to pass through it. The guard cells of the **stomata** are situated below the epidermal cells (Fig. 276). When water vapour passes out of the stoma it reaches a small air space protected from the atmosphere outside by the overhanging cuticle. This arrangement helps considerably to conserve the water supply of the tree. Beneath the epidermis is a layer of sclerenchyma to provide this long, thin leaf with the strength it needs to survive in all weathers. This layer is known as the **hypodermis.** It is interrupted beneath the stomata by small air spaces which communicate also with the mesophyll cells below.

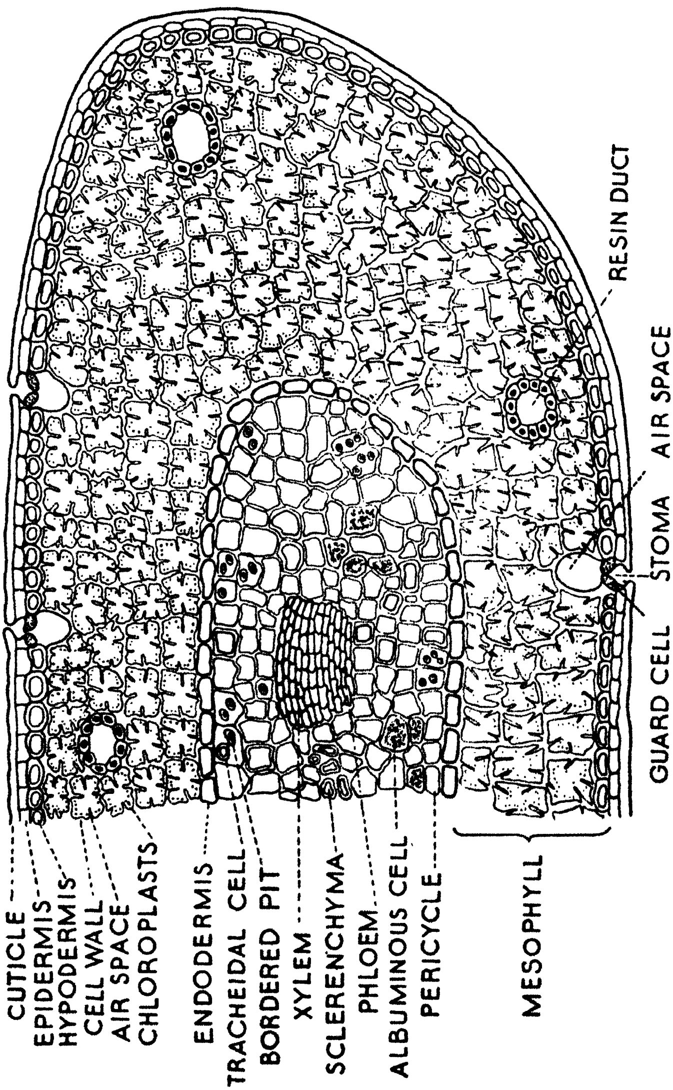


Fig. 276. Transverse Section of Leaf of Pinus.

The **mesophyll** cells are quite characteristic. They are roughly cubical in shape and the thin cellulose wall is folded inwards in several places (Fig. 276). This provides very narrow air spaces and a large area of cell-wall for the exchange of gases which plays such an important part in connection with the work of a green leaf. Inside the cell-wall there is a lining of protoplasm, in which are embedded the nucleus, many disc-shaped chloroplasts, and often starch grains. The centre of the cell is occupied by cell sap. A layer of resin ducts is present in the mesophyll.

The centre of the leaf is occupied by two **vascular bundles** in a large **pericycle** and surrounded by an **endodermis.** The vascular bundles are in some leaves connected by a band of sclerenchyma cells. Some of the pericycle are parenchyma cells, others are tracheidal and have bordered pits, still others are albuminous cells. The tracheidal and albuminous cells resemble those occurring in the medullary rays and are known as **transfusion tissue.** There are only two vascular bundles in these leaves, but their work is supplemented by the transfusion tissue.

7. THE CONES

In Pinus the reproductive organs are not produced on the foliage leaves, but on special leaves, which have become modified for this work only and collected together on a short stem to make a cone. These special leaves are called **sporophylls.** They are spirally arranged round the stem, or axis. Each sporophyll of the **pollen cone** bears two sporangia on its lower side (Fig. 277). These **sporangia** have two or three layers of wall cells without any special annulus cells. Inside the wall is the tapetum, and inside again many spore mother cells, each of which produces four **spores** by meiosis. These spores are commonly called **pollen grains.** Early in June the sporangia burst and numerous pollen grains are shed into the air, in which they float for a time. Each pollen grain is provided with

two wings by the inflation of its outer wall (Fig. 277). Some of these grains are destined to reach the young cones which will later form seeds.

In the **seed-bearing cones** the sporophylls are more woody than in the pollen-cones, and each has two parts, the outer known as the capellary scale and the inner as the ovuliferous scale (Fig. 278). On the upper surface of the ovuliferous scale two **ovules** develop. In an early stage the ovule is represented by a few cells, known as the **nucellus,** around which a cup-shaped envelope of cells, the **integument,** develops towards the axis of the cone. At this end a narrow space is left in the integument called the **micropyle** (Fig. 279). A cell near the micropylar end of the nucellus becomes conspicuous and divides to form a number of tapetal cells round one cell which is a spore mother cell. The latter cell by meiosis forms four cells, but only one of these will develop into a spore.

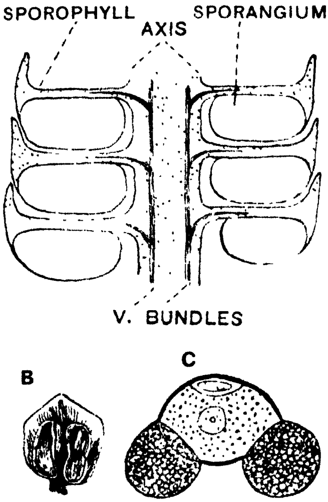


Fig. 277. MALE CONE OF PINUS. A, Part of a longitudinal section (diagrammatic); B, Sporophyll (under surface); C, Sporangium (two-celled stage, highly magnified).

In Pinus there are two different kinds of cone produced, each bearing spore mother cells and spores. To distinguish them the spores formed in the pollen cones are known as microspores, and the single, larger spore in the ovule as the macrospore, also called the embryo sac. The ovule is a macrosporangium surrounded by an integument. The production of two distinct spores is called **heterospory.**

Cones with ovules at this stage occur near the tips of the shoot at the end of May or early June. They have already passed through one winter. They are greenish-brown in colour, about half-an-inch long, and the sporophylls are slightly parted. It is at this time of the year that the microsporangia burst and the pollen grains are shed to be carried away by the wind. Some of these are brought to the ovuliferous cones and enter between the sporophylls. They are probably helped to enter the micropyle and reach the nucellus by mucilage given out at the micropyle. This is known as **pollination.** The sporophylls now become placed more closely together and during the next year the cones grow a good deal larger.

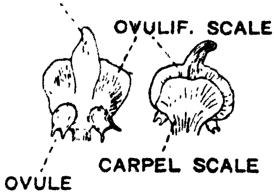


Fig. 278. Scales of Female Cone

From above and below (Carpel-scale = cover-scale).

After pollination has occurred the microspore germinates, forming the **male gametophyte.** It grows into the nucellus on which it feeds. This gametophyte is very specialised and consists of a very few cells. Two small cells are cut off at one end of the spore, while from the opposite side of the main cell develops a long tubular structure, the pollen-tube, which ramifies in the nucellus. Ultimately the main nucleus will divide forming a tube nucleus and an antheridial nucleus. The latter with its

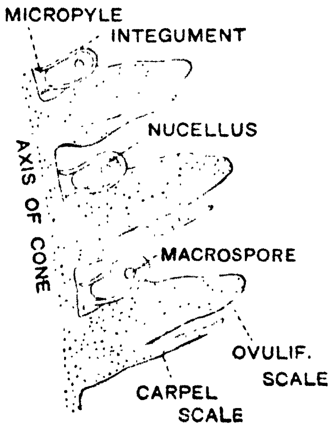


Fig. 279. Young Female Cone of Pinus.

(Part of a longitudinal section: diagrammatic.)

surrounding protoplasm divides to form a stalk cell and a generative cell from which two male gametes will be produced (Fig. 280). The male gametophyte of Pinus lives parasitically on the parent sporophyte, and the parts are reduced and specialised to effect fertilisation economically.

The macrospore is retained in the ovule on the parent tree and not shed. The **female gametophyte** is developed inside the ovule. The macrospore nucleus divides and the

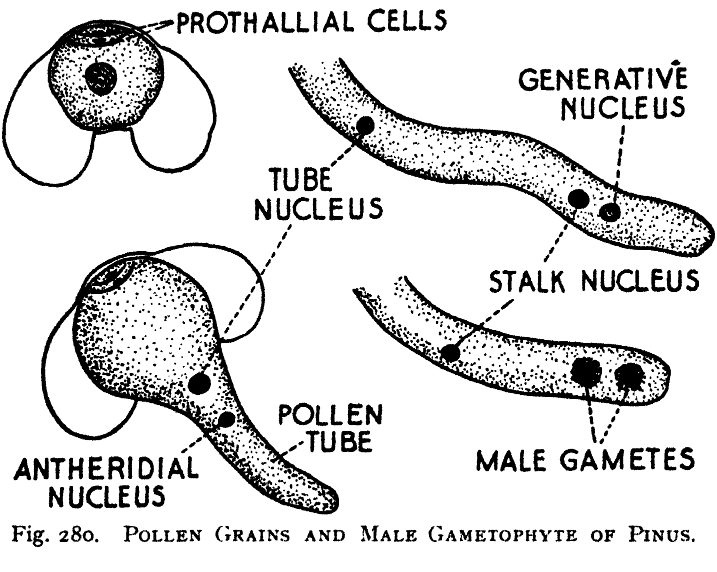


Fig. 280. Pollen Grains and Male Gametophyte of Pinus.

two nuclei so formed divide again, and so on. This goes on very regularly until 256 nuclei are produced within the macrospore wall. These have collected more densely near the wall than in the centre. From the edge towards the centre cell-walls are laid down, so that a mass of parenchymatous tissue is produced (Fig. 281). This is the female gametophyte or prothallus. It contains no chlorophyll. It has encroached upon the nucellus, but the integuments have grown with the gametophyte. At the micropytar end

two or three archegonia develop. Each **archegonium** consists of a very large oosphere and a small neck. The oosphere contains many vacuoles and it is surrounded by a layer of small cells called the "nutritive jacket." The "jacket" is continuous with the two or three tiers of small neck cells. A ventral canal cell is formed but no neck canal cell. This stage of development has been reached by June in the second year of the life of the cone. By this time the pollen tube has penetrated the nucellus so that its tip has reached the prothallus and ultimately finds the neck of the archegonium. The nuclei formed in the pollen tube have migrated to its tip, and each has collected around it some protoplasm. One male gamete passes from the pollen tube into the neck of the archegonium to the oosphere

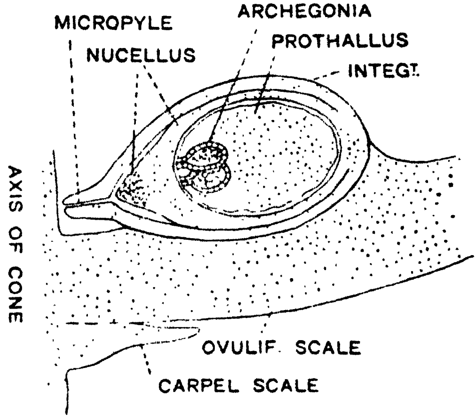


Fig. 281. Ovule of Pinus.
(Longitudinal section—about the time of fertilisation.)

which it enters and with which it fuses making an **oospore.** Thus **fertilisation** is effected a year after pollination. Not only was the macrospore retained on the parent, but here the female gametophyte developed and bore the female gamete to which the male gamete was brought without being liberated into the world outside the plant.

During the third year of development of the woody cone the oospore forms an **embryo** sporophyte and the ovule becomes a seed. It is because an embryo is formed inside

the macrospore that the latter is also called the embryo sac. The nucleus of the oospore moves to the end farthest from the micropyle, and by two mitotic divisions four nuclei are formed, which place themselves in one horizontal plane (Fig. 282). Each of these nuclei divide again so that two tiers of four are produced. The basal ones become

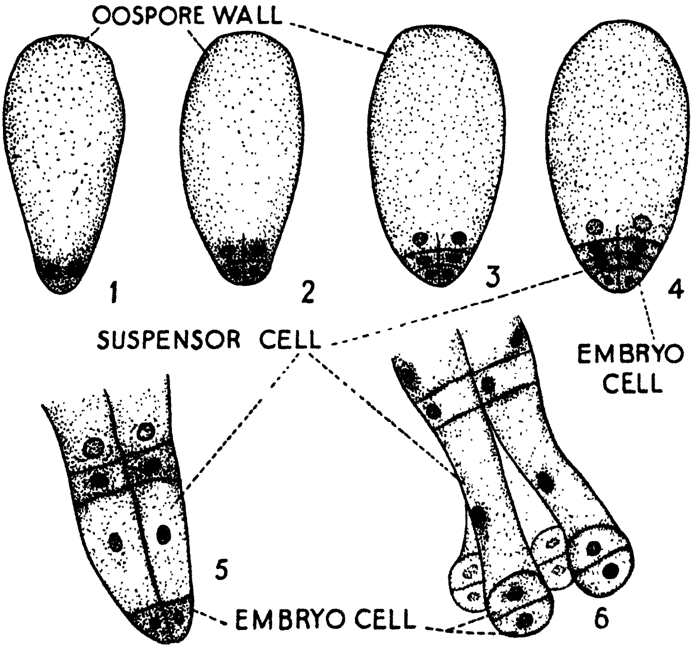


Fig. 282. Stages in the Development of the Oospore of Pinus. Only Two Nuclei of the Four in each Tier shown.

separated by cell walls, and divide again making three tiers of cells. Another division occurs forming four tiers each with four cells, which become separated by cell-walls except the upper ones which are in contact with the large volume of the oospore which contains food. The cells next to these undergo very little change; the next become

considerably elongated, because they move the lowest cells, from which the embryo actually develops, further and further into the gametophyte. As only a small part of the oospore forms the embryo the development is meroblastic. The gametophyte is now the feeding tissue for the developing embryo and to such tissue the term endosperm has been given. Although there are four basal cells, only one eventually develops an embryo. The elongating cells are called suspensors.

From the embryonal cell the following structures develop: (1) the beginning of the primary root or **radicle**; (2) the young stem and foliage leaves or **plumule**; (3) the **hypocotyl** which joins together stem and root and bears eight or more special seed-leaves or **cotyledons.** These constitute the embryo sporophyte which occupies the central area of the endosperm, some of which is not used until the seed germinates. The nucellus has been crushed but the integument has developed into a protective covering now called the **testa,** in which the micropyle still persists.

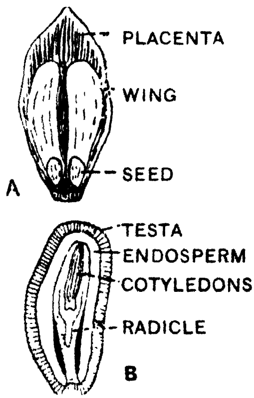


Fig. 283. Seed of Pinus. A, Surface view: B, Longitudinal section.

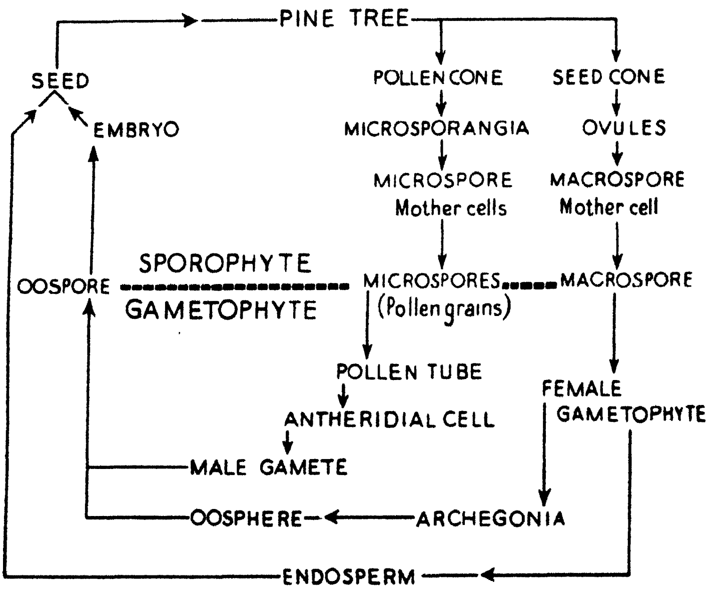
It is this structure known as a **seed** and formed from the ovule, which is shed from the parent tree and rests through the winter. Before it leaves the cone the testa develops a long, thin wing towards the outside of the cone (Fig. 283), and the sporophylls separate so that the wind can blow the seeds away.

8. LIFE-CYCLE OF PINUS

Pinus exhibits a regular alternation of generations. The double number of chromosomes present in the sporophyte

is reduced during the formation of the asexual spores. Both gametophytes have the reduced number, and the union of the gametes restores the double number for the next generation. In a seed the testa is made from cells of the parent sporophyte, the endosperm is the remains of the female gametophyte, and the embryo is the new sporophyte; thus three generations are represented.

The life-cycle of Pinus may be represented briefly:—



This cycle should be compared with that of a fern, Chapter XVI., and also later with that of a flowering plant, Chapter XVIII., so that the sequence of changes may be appreciated. They involve the change from the homosporous condition of the typical fern to heterospory; pollination, the carrying of the male gamete to its destination in a pollen tube; and the formation of a seed.

9. THE SEEDLING

After its winter rest in the soil the seed germinates. Water and air are absorbed through the micropyle. The cells of the embryo increase in size and become active. The testa is burst and the radicle emerges and makes its way into the soil. Shortly afterwards the hypocotyl lengthens and appears in an arched form above the soil. As the hypocotyl straightens itself the cotyledons in the endosperm and testa are pulled out of the soil. The testa soon falls off, and when the endosperm has all been absorbed by the cotyledons they expand as a circle of green leaves with the plumule in the centre (Fig. 284). When the cotyledons are brought above the soil in this way and function as foliage leaves for a time, they are said to be **epigeal.**

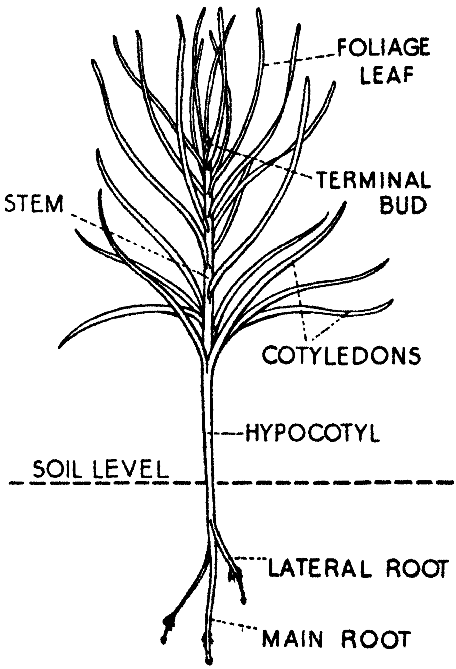


Fig. 284. PINUS SEEDLING.

Later the stem and true foliage leaves are formed. The latter at first occur singly on the stem, but as time goes on dwarf shoots are formed and the characteristic features of *Pinus sylvestris* attained.

CHAPTER XVIII

THE CHERRY TREE

1. INTRODUCTORY

The generic name of cherry is *Prunus*. There are four species of this genus which occur wild in Britain, *P. Cerasus* being the wild cherry. Very similar to it is *P. Avium*, commonly known as Gean, while *P. Padus*, the bird cherry, is distinctive in the way its flowers are arranged. The blackthorn or sloe, so common in hedges, is also a wild species of Prunus, namely *P. Spinosa*, so called on account of its spines. Blackthorn flowers very early in spring, before it shows sign of leafing, and the clusters of small, white blossoms are conspicuous against the black, thorny twigs.

Given a wild plant, man, by inter-breeding, selection, and grafting, can often alter its characters somewhat. This he does with the intent of obtaining more beautiful blossom, or, as in the case of the cherry, better fruit. All our cultivated varieties of cherry have probably been produced from the gean and the wild cherry. The fruit of the former may be either black or red, sweet or bitter, while the wild cherry has always a red fruit, with an acid taste. Bird cherry has a small, black, and very bitter fruit, with a wrinkled stone.

Blackthorn has probably given rise to most of our cultivated plums.

Cherries have also been cultivated by man in order to give ornamental blossom, for instance, the large, double blossoms.

2. SEED AND SEEDLING

If we crack the stone in the middle of the edible cherry fruit we get out the seed. It is covered by a very thin skin, the **testa,** which is easily peeled off. In order to examine

the seed, it will probably be an advantage to leave it soaking in water for twenty-four hours. Some bean, or pea, seeds may be soaked and examined at the same time, as these have precisely the same structure and show the parts more distinctly. Before removing the testa, notice a scar, the **hilum**, where the seed was attached to the fruit. At one end of this is a tiny hole called the **micropyle** (Fig. 285). When the seed is surrounded by moisture it enters readily through the micropyle. At first the testa becomes wrinkled, because it takes up moisture quickly. This causes the cells comprising it to stretch, so that the whole testa becomes larger and no longer fits the seed tightly. More

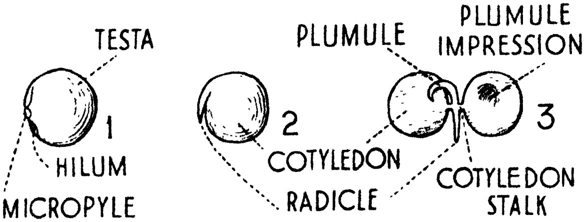


Fig. 285. PEA SEED.
1, External appearance; 2, Testa removed; 3, Cotyledons separated.

slowly the moisture enters the cells of the rest of the seed, so that it all swells and stretches the testa tightly again.

On removing the testa, the seed inside is found to consist of two halves. These are both attached by a short stalk to an object lying between them (Fig. 285). This consists of the primary root of the future plant, the **radicle,** and the shoot, the **plumule,** both in miniature. These two naturally adjoin one another, since the primary root and the main stem of a plant are continuous with one another and form the axis. The plumule consists of a very small piece of stem and one or two leaves, very minute, but perfectly formed. The two halves enclosing the plumule and radicle are thick, white, and fleshy, and do not resemble

or suggest leaves, but they are actually a pair of leaves attached to the bottom of the plumule. They are called seed leaves, or **cotyledons,** and their different appearance is due to their special function of containing a store of food, which the young plant may use until it is large enough to obtain some for itself. A young plant is called an **embryo,** and in the seeds examined the embryo occupies the whole seed.

It is sometimes possible to get seeds, especially of a wild species of cherry, to germinate if they are sown in pots of

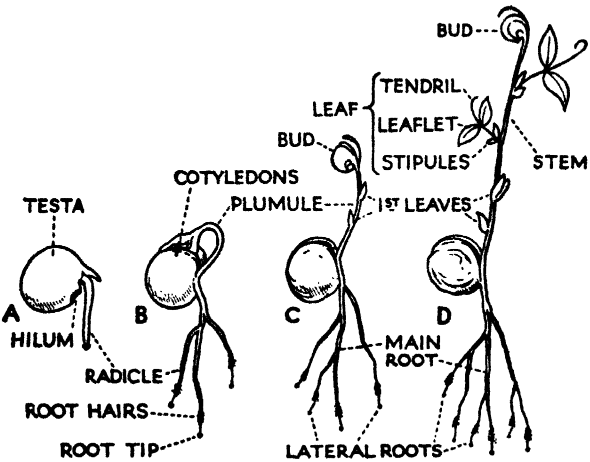


Fig. 286. PEA.
Stages in Germination.

soil. Some runner beans and edible peas might be sown at the same time, as these germinate in the same way. These should be allowed to soak before planting. They can be put in a glass jar lined with damp blotting-paper, between the glass and the paper, so that the whole of the **germination** can be watched. The beans and peas should be put in the jar with the hilum vertically up and the micropyle at the lower end of the hilum. The first thing to appear is the radicle, and this pierces

the testa near the micropyle and grows vertically downwards (Fig. 286).

The tip of the radicle may be seen to be protected by a root cap. Its presence will be certainly determined by mounting a root tip whole and examining it with a microscope. Just a little way behind the root cap the surface of the radicle is clothed with a mass of hairs called root hairs; the shorter are nearer the tip. The hairs absorb water and food materials from the soil. They are well seen on the radicles of mustard seedlings grown on damp blotting-paper, or on a wet sponge hung in a bell-jar (Fig. 287). The root hairs soon become worn out, but the region immediately behind the tip continually elongates and produces new root hairs.

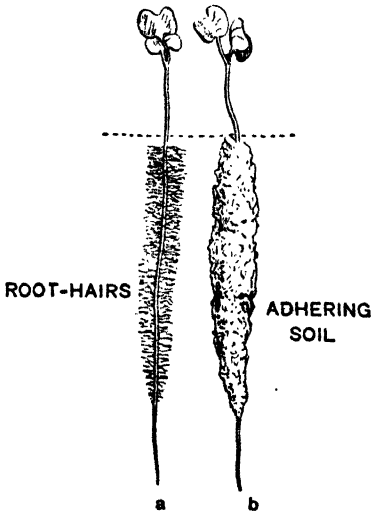


Fig. 287. Mustard Seedlings.

When the plumule emerges it is hooked. The hook is the stem, and when the cherry seedling reaches this stage, it shows above the surface of the soil as a tiny arch. It is obvious that this arched stem has pushed its way through the soil, and this is an advantage, because it is strong enough to do so without damaging itself. At this stage a cherry seedling may be dug up and examined (Fig. 288). By the time the plumule has well developed the primary root has several, spirally arranged, lateral roots appearing at the seed end. Since they arise from a primary root, these branch roots are called secondary

roots. Each has its own root-cap and root hairs. Having forced its way successfully through the soil, the stem straightens and shows signs of the leaves. The place on a stem from which a leaf grows is called the **node,** and the bare stem between two nodes, the **internode.** A properly-developed leaf does not occur at once. The

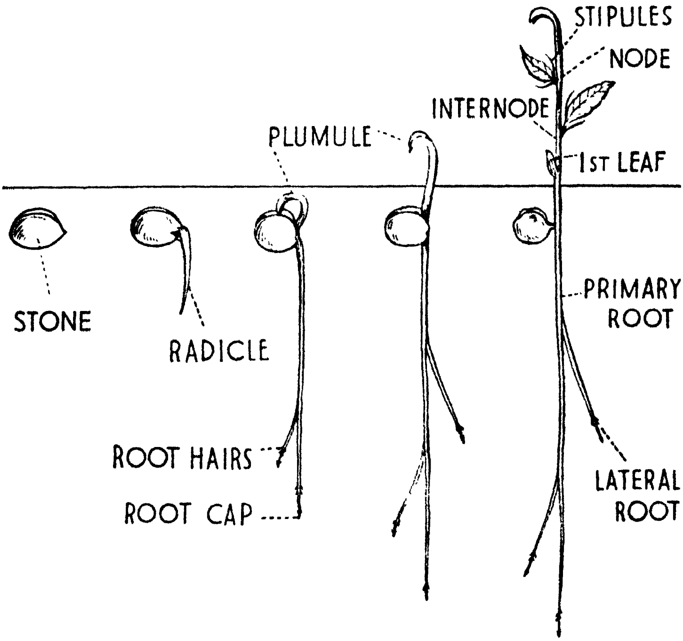


Fig. 288. Germination of Cherry.

leaves have a pair of thin out-growths, stipules, from the base of the stalk.

3. EXTERNAL FEATURES OF THE TREE

The wild species of Prunus are little more than shrubs, but shrubs and trees are akin to one another in possessing **woody twigs.** A plant with a shrubby habit usually sends

up a number of separate stems from the root, and this occurs in wild cherry, but gean and bird cherry, with one main trunk, have a proper tree habit (Fig. 289).

The main trunk of a cherry tree divides into two or more unequal branches. This gives the tree a somewhat spreading habit and flat top. In a young tree the bark is dark grey and smooth, except for ring-like markings at intervals on it, but later it becomes darker in colour and furrowed.

Fig. 289. PRUNUS AVIUM.

The **winter twig** of cherry should be examined (Fig. 290, A). The buds are conspicuous objects. They are dark-brown, rather sticky, and a number of **scale leaves** are visible. They overlap one another, the smallest being the outermost one. They should be removed one by one and placed in order on a sheet of paper. It will be found that they are spirally arranged and very close together on a short piece of stem. The scales further in become taller and greener, until they have only a brown tip, or perhaps no brown colour at all; and within these are true foliage leaves (Fig. 291), very small and pleated along the veins. The bud scales are modified leaves, which protect the young foliage leaves.

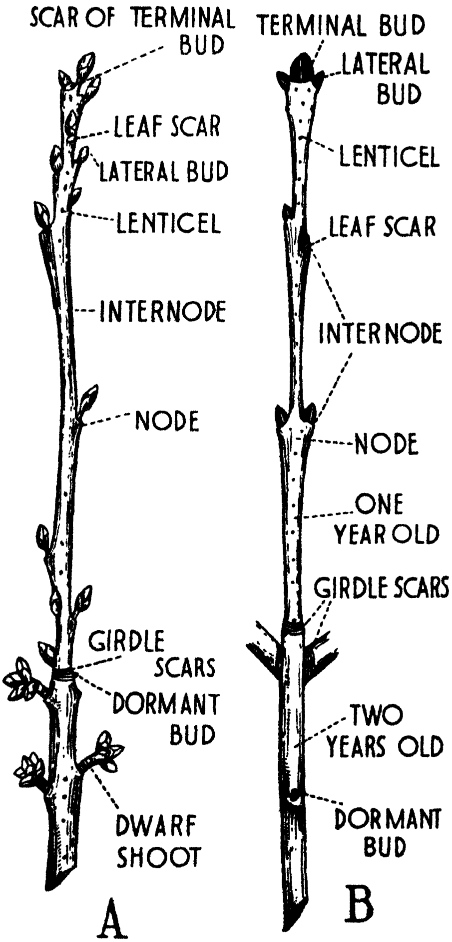


Fig. 290. A, Cherry Twig; B, Ash Twig.

On the twig are a number of marks. Below each bud is an oval-shaped **leaf scar,** in which a number of dots form a crescent. Since buds grow in leaf axils, a leaf scar naturally occurs beloweach. The dots in the scar are made by the vascular strands in the leaf stalk. **Leaf fall** in autumn does not occur because the leaves are just killed off by the cold weather, but the tree deliberately cuts them off, because it cannot afford to keep them during the winter, when water is difficult to obtain from the cold soil. A layer of cork, called the absciss layer, grows across the base of the leaf stalk, but not across the vascular strands (Fig. 292). Since cork is impermeable to water, moisture can now only pass from the stem into the

leaf along the vascular strands. Along these, also, valuable substances pass back from the leaf into the stem, so that they shall not be wasted by being left in the fallen leaves. Finally the cork layer splits, so that the leaves hang on only by the veins. Then a high wind, or a frost, causes these to snap, and the leaf falls. While some of the substances are passing out of the leaf into the stem, it changes colour, giving us wonderful autumn tints, in the case of the cherry a glorious red.

All over the twig are dots, which are openings called **lenticels,** in the outer covering of cork. Cork is impervious to gases, and therefore, must have in it openings, if the twig is to breathe.

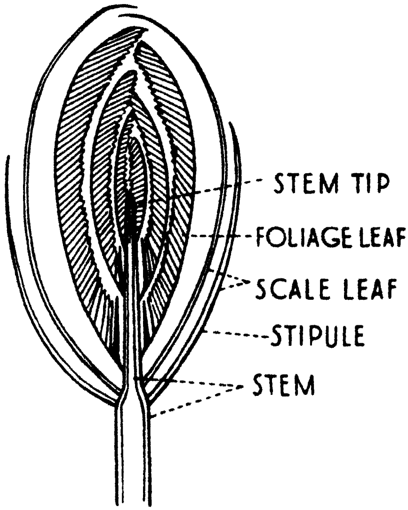


Fig. 291. CHERRY TREE.
Longitudinal section of Bud.

At intervals on the twig there are groups of ring-like markings called **girdle scars,** because they encircle the twig. Each group consists of a number of narrow scars very close together. They are left by the outer bud scales, when they fall on the opening of the bud. There is therefore a group at the base of each branch, since every branch has grown from a bud. On the main twig the number of groups of girdle scars indicates its age, since the end bud on the twig forms a group each spring.

The twig is characterised by a number of short branches each having a number of buds at the end. These have one or

more groups of girdle scars, therefore they must be two or three years old. Since they have obviously grown only a very short amount in one year they are called **dwarf shoots.**

If the end bud on the twig is examined, a leaf scar will be seen on one side of it, and possibly a smaller scar on the other side (Fig. 290, A). This bud must have grown in the axil of a leaf and is therefore an **axillary bud.** There is no bud at the true end of the twig, that is, no terminal bud; it shrivelled away when quite small, leaving the scar. Since an axillary bud grows into a branch, the main part of our Cherry twig really consists of a number of branches which have grown so that they appear to form one continuous stem. This type of growth is called **sympodial.** A twig with a true terminal bud, *e.g.* Ash (Fig. 290, B), is said to have monopodial growth.

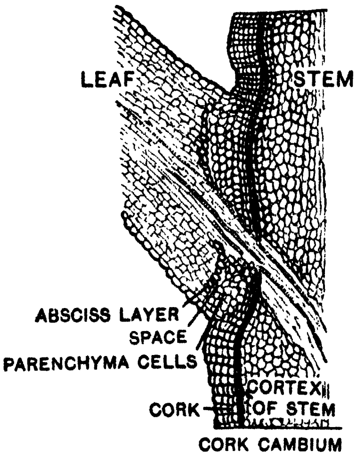


Fig. 292. LEAF-FALL.
It will be seen that the leaf is practically hanging on by its vascular bundle.

In addition to those which are normal, a number of very small buds occur, chiefly amongst the girdle scars, since they grow in the axils of bud scales, but they may occur in the axil of an ordinary leaf scar. These never develop unless a large bud is injured, and are therefore called **dormant buds.** They may remain for many years and then be called into activity; for instance, if the tree is lopped.

Fig. 293 shows stages in the opening of a bud. The scales separate owing to the lengthening of the stem, which gradually carries up the leaves. These enlarge and unfold.

The **leaf** has pointed teeth of two sizes, regularly placed along the margin, and all pointing towards the leaf tip. Since the teeth are like those of a saw, the margin is said to be serrate. Fig. 294 indicates the three parts of the leaf, namely blade, petiole, and base. The leaf figured is that of a double-flowered cherry tree. On the petiole there may be a tiny cup-like structure which secretes nectar, the sweet, sticky juice sought by insects. The leaves are spirally arranged on the twig. The thin **blade,** or lamina, is traversed by veins, which are firmer because they consist

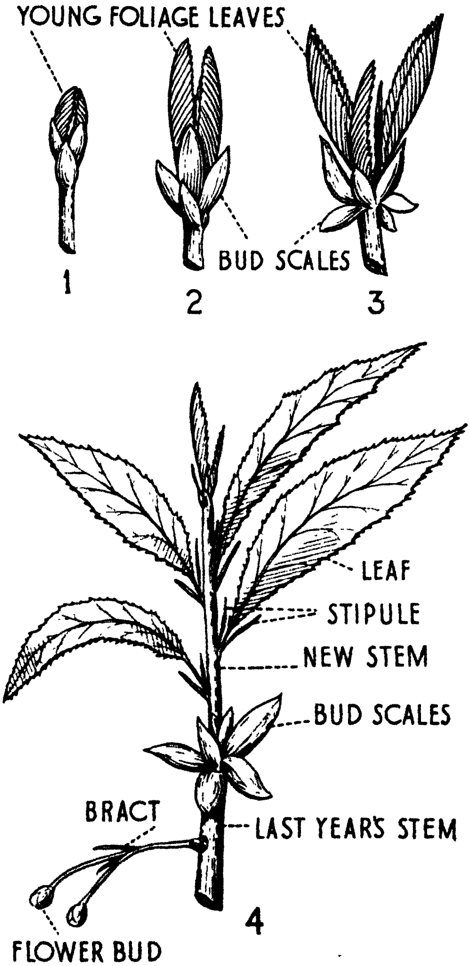


Fig. 293. CHERRY TREE.
Stages in the opening of the buds.

partly of wood. There is one main vein, rather larger than the rest, down the centre of the blade. Branches arise from this and these branch again. The ends of the finest branches unite with others, and thus the veins form a network in the leaf blade. Since the main vein with the branches suggests a feather, the **veins** are said to be **net pinnate.** The leaf-stalk is called the **petiole,** and this has a **base,** by which it is firmly fastened to the stem.

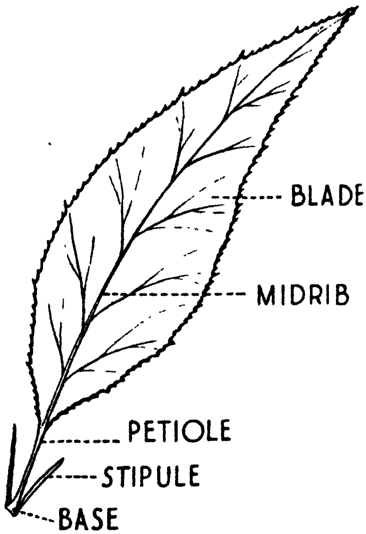


Fig. 294. CHERRY LEAF.

4. ANATOMY

A transverse section of the stem near the top of a seedling, in its first year, may be cut and mounted for examination under the microscope. The sections will be rather small, and perhaps difficult to cut; very young sunflower stems may be cut instead. The youngest region of a stem is always at the tip. A number of oval-shaped structures, arranged in a ring, will be obvious. These are the veins, or **vascular bundles**; they mark off a central part, the **pith,** from an outer part, the **cortex** (Fig. 295). The pith consists of parenchyma, and so does the inner part of the cortex. The outer part of the cortex is collenchyma, as described in Chapter XII. Some of the cells in the outer cortex contain tiny, oval chloroplasts. The cells of the skin, or **epidermis,** are somewhat rectangular and have no chloroplasts. The outer walls of the epidermal

cells are covered by cutin, which prevents the too ready escape of water vapour. At intervals in the epidermis there are pairs of guard cells, forming a stoma. In sunflower stem hairs grow out from the epidermis. The innermost layer of the cortex consists of a row of cells, which each have a piece of thickening in the centre of their radial walls. They also contain starch grains and form the **endodermis**, that is a kind of inner skin enclosing the vascular bundles. The layer of cells immediately next to them is called the **pericycle.** Passing between the vascular

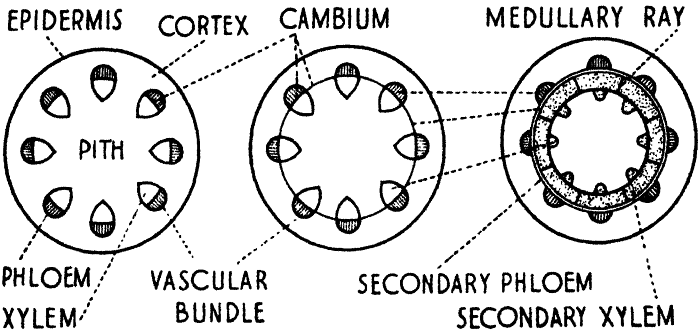


Fig. 295. PLAN OF TISSUES IN DICOTYLEDON STEM TO THE END OF THE FIRST YEAR.

bundles are rays of parenchyma cells connecting pith with cortex. They are called **medullary rays** (medulla = pith).

This arrangement of vascular bundles inside an endodermis is called a **eustele.** It is thought to have arisen from a protostele, which, by increase in girth, developed parenchyma in the centre and then the xylem and phloem became separated into groups instead of remaining continuous.

The vascular bundles (Fig. 296) consist of wood or xylem, cambium, bast or phloem, the **xylem** being next to the pith. The majority of the elements of the xylem have lignified, that is, woody walls. Those which are most conspicuous, on account of their large diameter, tend to be arranged in

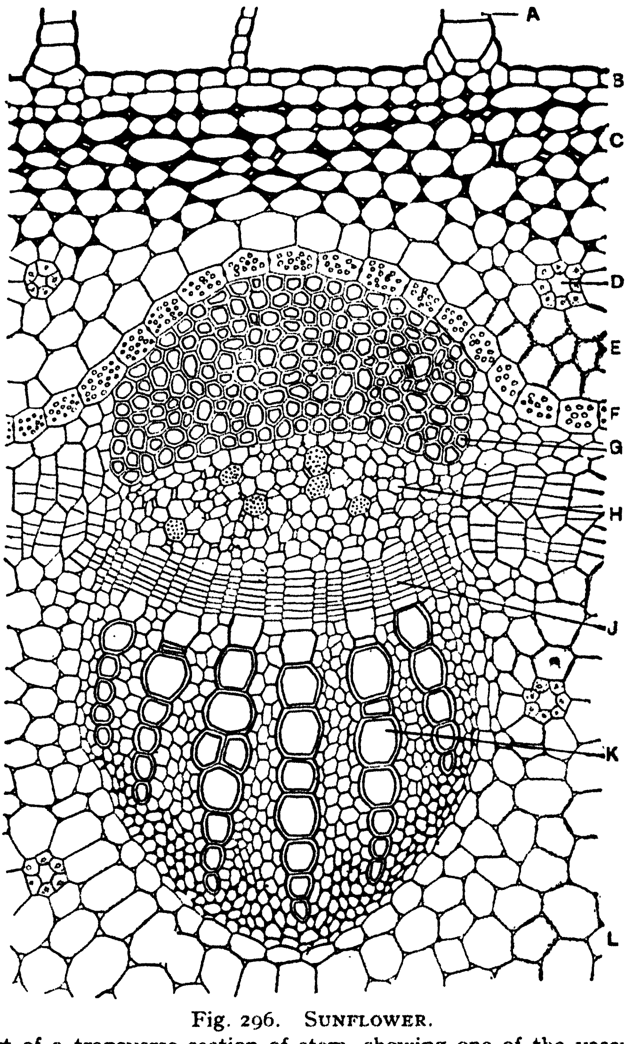


Fig. 296. SUNFLOWER.

Part of a transverse section of stem, showing one of the vascular bundles. A, Hair; B, Epidermis; C, Collenchyma of cortex; D, Resin duct in cortex; E, Parenchyma of cortex; F, Endodermis; G, Sclerenchyma; H, Phloem; J, Cambium; K, Xylem; L, Intra-stelar parenchyma (note the resin-ducts).

rows, in which the narrower are immediately next the pith. These latter were the first formed, and constitute the **protoxylem.** Interspersed with these there are smaller elements, some of which have lignified, and some have cellulose, walls. The **phloem** consists of two distinct parts. Immediately next to the cortex is tissue of which the elements are all similar and with lignified walls. This is hard bast. The soft bast is composed of elements with cellulose walls, some of which are rather wide. Each of

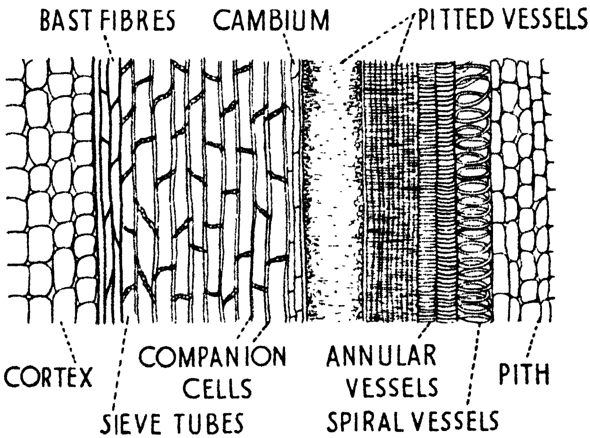


Fig. 297. CHERRY.
Longitudinal section of stem.

these wide ones has a smaller one by its side. Between the xylem and phloem are a few rows of brick-shaped, meristematic cells forming the **cambium.**

By cutting a longitudinal section of the stem more can be discovered about the elements of the xylem and phloem. In the xylem are long, wide tubes continuing for a great distance before they finally have a wall across them. They are called **vessels** (Fig. 297). A longitudinal section also shows that the wall does not consist of solid lignin.

A vessel has been formed from a row of cells in which the cross walls have disappeared. These cells had cellulose walls, and the lignin was laid on the cellulose. During this process the protoplasm was used up, so a vessel is really non-living. In the largest vessels the wall is almost entirely lignin, only having small spaces, or pits, in it; these are pitted vessels. In others the lignin is in the form of a network, making reticulate vessels. In the smallest, those which form the protoxylem, it is laid down either in rings, or in a spiral, giving annular and spiral vessels, usually the latter. Those elements of the xylem, which have lignified walls and are not vessels, are long and narrow, with pointed ends. They are called **fibres,** and their walls have very minute pits. The remaining elements consist of parenchyma cells, forming the **xylem parenchyma.**

The hard bast consists of **bast fibres,** similar to the xylem fibres. The wider elements in the soft bast have also been formed from rows of cells in which the cross walls have not entirely disappeared, but become perforated, so that they have the appearance of sieves; hence the term **sieve tubes.** By the side of each sieve tube is a row of small, parenchyma cells, the **companion cells.** The remainder consists of **phloem parenchyma.**

A vascular bundle has two sets of tubes, xylem vessels and sieve tubes. In the former, the food solution taken in at the root rises, and in the latter, food built up in the plant descends. The lignified xylem and bast fibres also lend strength and rigidity to the stem.

Unless the transverse section was taken very, very near the tip of the stem, where it is as young as possible, the cambium is seen to extend across the medullary ray stretching from bundle to bundle, and forming a complete ring (Fig. 295). The cells composing the cambium are capable of very active division. The new cells, which they form on the cortex side, become phloem elements, and those on the pith side, xylem elements. Hence there

soon results a ring of xylem and a ring of phloem; and the phloem and xylem in the original bundles become farther and farther apart (Fig. 295). If a transverse section be taken lower down the stem, where it is older,

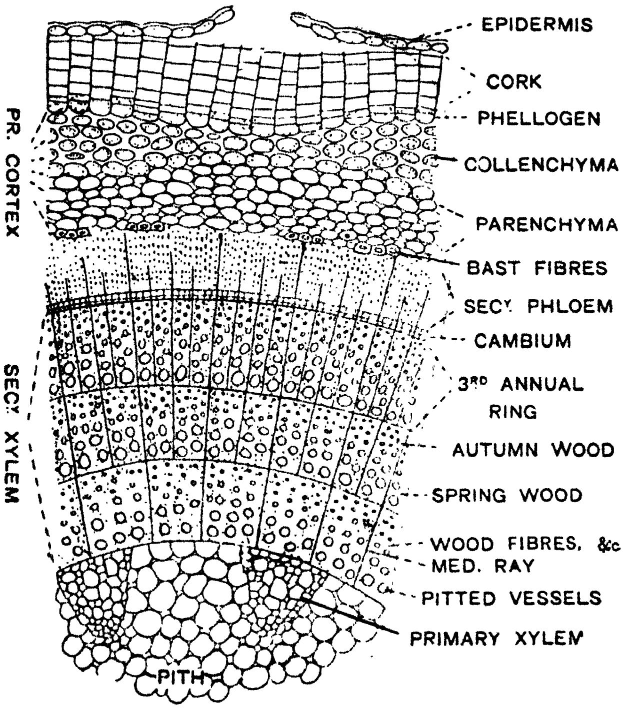


Fig. 298. Part of a Transverse Section of a Three-Year Old Internode of a Dicotyledonous Stem.
(*E.g.* Elder.)

the arrangement shown in this figure will be found. The ring of xylem is called **secondary xylem**, and that of phloem, **secondary phloem**, as compared with the primary xylem and phloem in the original bundles. The original medullary rays are still to be found, because in certain places the

new cells made by the cambium remain parenchyma cells, but the rays are much narrower than in the young stem.

Finally, a transverse section of a Cherry twig, where it is three years old, as shown by the girdle scars, should be taken. Here the pith is very much smaller, and the quantity of wood has increased much more than that of the phloem (Fig. 298). Groups of primary xylem are still distinguishable round the pith, but it is difficult to find any trace of primary phloem, because it has become so split up by the large amount of growth within it. There may be small groups of hard bast discernible on the inner side of the cortex. The xylem consists of three distinct rings. This appearance is due to the fact, that in three places several layers of very narrow vessels occur immediately next to wide vessels. The narrow vessels are formed in the autumn and the wide in spring. The function of the xylem vessels is to conduct food solution taken in by the root up to the leaves. In the spring a large quantity of food solution is needed quickly, because of the rapid growth of the opening buds; hence the wider tubes to carry it. As the season advances, the increase in the number and size of parts needing sap ceases. The vessels have already developed, so that as growth continues, the new vessels are made smaller and with thicker walls. This is because they also supply a good deal of strength, the increased demand for which arises when the leaves are fully grown. In the autumn a few still smaller, thicker-walled vessels are made, and in the winter growth

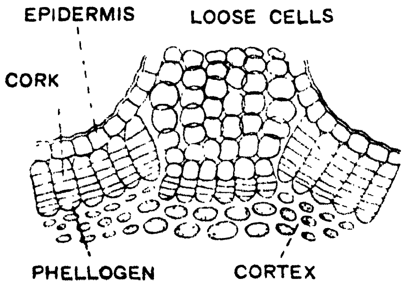


Fig. 299. Section through a Lenticel.

ceases. Thus by this regular rhythm of growth the largest vessels follow the smallest.

In this way a distinct ring of xylem is formed each year. It is spoken of as an **annual ring**, and by counting the annual rings we have the age of the twig. The annual ring last formed is, of course, the one next the cortex. The xylem is crossed by narrow rays of parenchyma cells, the medullary rays. Those originally present extend from pith to cortex and are called **primary medullary rays.** Some rays are formed in each annual ring and continued in the following year, so that some extend across only the two outer annual rings, and some across only the outermost one. These are **secondary medullary rays.**

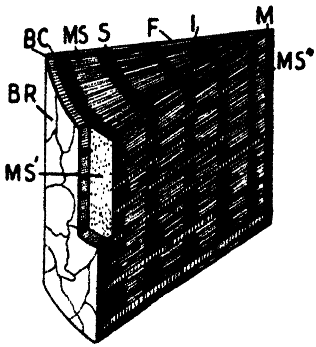


Fig. 300. A Young Tree Trunk Cut in Three Directions.

B, Bast; C, Cambium; S, Autumn wood; BR, Bark; F, Spring wood; MS, MS′, MS″, medullary rays in transverse, tangential, and radial view; I, Meeting of autumn and spring wood.

In a three-year-old stem a new tissue has appeared round the outside. As the stem increases in width, owing to this secondary growth, the epidermis becomes too small and splits. This would leave the cortex exposed and the stem liable to lose water, but before the epidermis splits a layer of cambium cells, called **phellogen,** forms below it. These cells cut off on their outer side layers of brick-shaped cells, which lose all their contents, and the walls of which are impregnated with a substance called suberin. These cells form **cork,** which is impermeable to gases just as it is to water, and therefore escape of water vapour from the stem is prevented. At intervals the cork cambium forms rather round, parenchyma cells, with spaces between them

through which gases can pass. These are the lenticels seen on the surface of the twig (Fig. 299).

In order to learn more about the medullary rays longitudinal sections of the stem are necessary. These may be cut through the pith, that is along a radius, or parallel to a

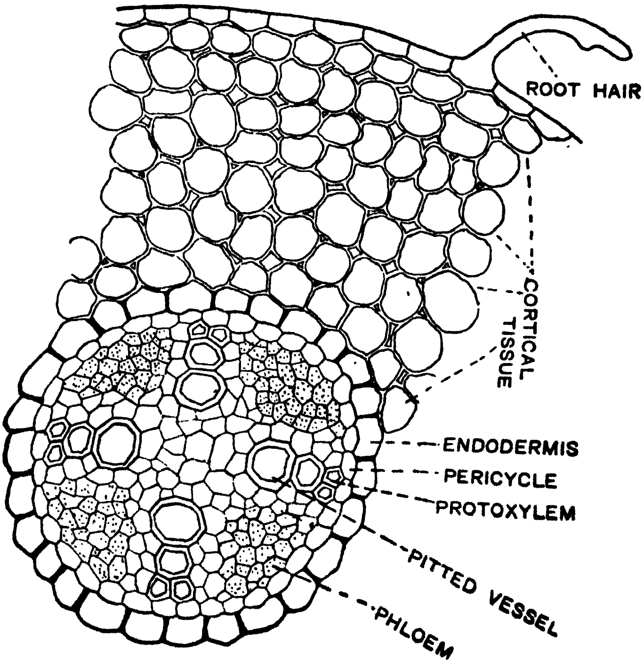


Fig. 301. TRANSVERSE SECTION OF A YOUNG DICOTYLEDONOUS ROOT WITH TETRARCH STELE.

tangent to the circular stem, giving us longitudinal radial, or longitudinal tangential, sections (Fig. 300). The radial section shows that the rays are not many cells deep, while in the tangential section the cut ends of these shallow bands are viewed. Medullary rays are in fact rather like wedges of parenchyma cells inserted into the hard wood.

The structure of a **root** can be studied in a transverse section of either the young Cherry root, or the young Bean root. The xylem forms a star in the centre. There may be a few thin-walled cells in the centre, but these do not really form a true pith. They are xylem elements of which the walls have not become thoroughly lignified. The small vessels of the protoxylem occur at the points of the star. Since the xylem star in Fig. 301 has four points, the root is said to be tetrarch. The number of protoxylems is

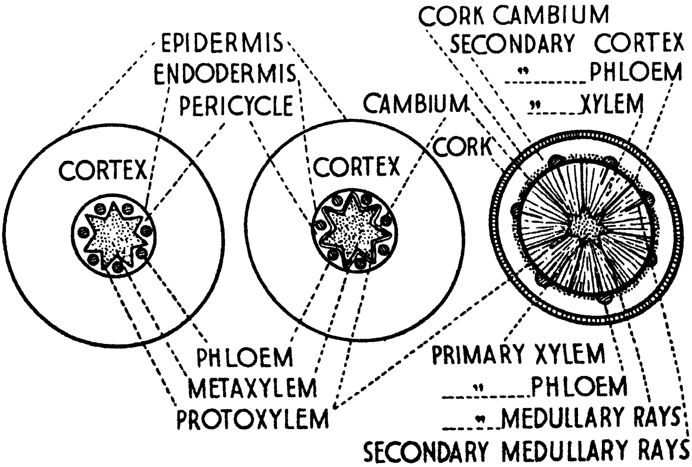


Fig. 302. Plan of Tissues in a Dicotyledon Root.

liable to vary from two to about six. Between the points of the xylem occur groups of phloem. Surrounding the xylem and phloem is the pericycle and outside this the endodermis. The cells of the latter gradually thicken three of their walls, the remaining thin one facing the cortex. This helps to ensure that the food solution travels straight up in the root and does not pass to too great an extent across it. Some must pass into the cortex and therefore there is, here and there in the endodermis, a cell

with all thin walls called a passage cell. The cells of the epidermis grow out to form root hairs.

The lateral or **branch roots** arise in the pericycle opposite to the protoxylems, so that they must push their way across the cortex. Because they arise from the central part of the main root their origin is said to be **endogenous** (Gk. *endo* = inner: *genesis* = beginning).

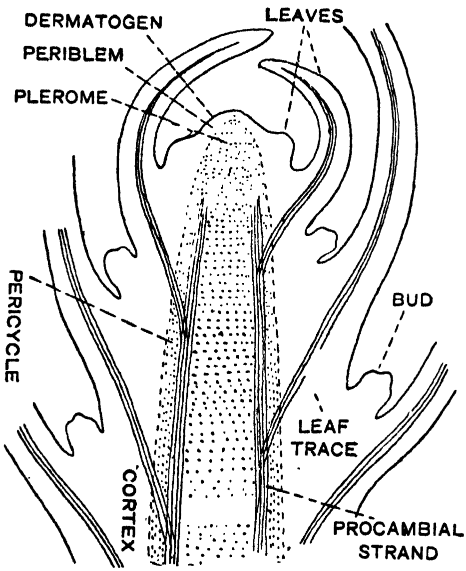


Fig. 303. Growing-Point of a Stem. (Longitudinal section—diagrammatic.)

A section a little higher up, where the root is older, reveals between the xylem and phloem a cambium (Fig. 302) which is made continuous by development of pericycle cells. This naturally follows the outline of the xylem, but it forms a smaller quantity of tissue opposite the protoxylems than between them, and therefore soon becomes a circle. The structure of a root that is several years old begins to resemble closely that of a stem, but it can be distinguished as a root by the solid, central, star-shaped primary xylem, and the wider and more prominent medullary rays opposite to each protoxylem. These are called primary, but they are not truly primary since they have only appeared with the secondary xylem.

The structure of the young stem differs from that of a young root because of the different strains to which it is submitted. The wood gives the organ strength. A stem is submitted to a bending strain, since it is buffeted by the wind. Hence the ideal arrangement is a hollow cylinder of wood with soft tissue in the centre. The root on the other hand must resist the pulling strain of the aerial part of the plant, and therefore needs a rod of wood.

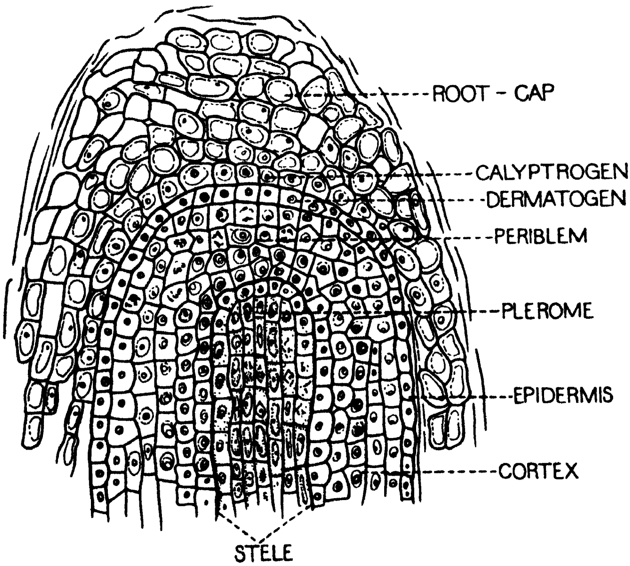


Fig. 304. LONGITUDINAL SECTION OF ROOT-TIP.

The structure of the youngest region of stem and root, namely the **apex**, may be seen in a longitudinal section. Here the cells are all as yet meristematic, gradually becoming parenchymatous. Three regions, which give rise to epidermis, cortex, and vascular tissue, are differentiated. Fig. 303 shows these regions and indicates the names applied to them. In a root tip (Fig. 304) there is

an extra region, namely the root cap. The section of the stem shows that its branches arise as outgrowths from the dermatogen and periblem. Each develops its own plerome strand, which runs into the stem and joins on to the plerome there. This mode of origin is called **exogenous,** as compared with the endogenous origin of branch roots.

A transverse section of the **leaf** (Fig. 305) reveals an upper and a lower **epidermis** of rectangular cells. There may be a few **stomata** in the upper epidermis, but the majority are in the lower. The places where they occur

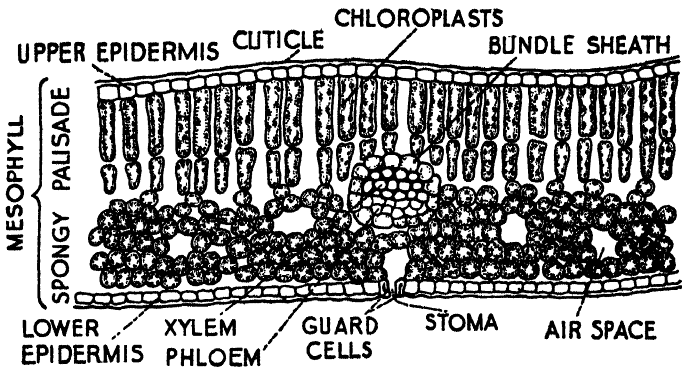


Fig. 305. CHERRY.
Transverse section of leaf.

may be located by the presence of an air space immediately behind them. Immediately below the upper epidermis there are closely packed, rectangular cells, either one or two layers. These are parenchyma cells and contain numerous, small, oval chloroplasts. The remaining cells of the blade are parenchyma, but rounded and interspersed with large air spaces, and they contain fewer chloroplasts. These two slightly different tissues are the **palisade** and the **spongy mesophyll.** Most of the veins will be cut obliquely, but the main vein should be transverse. They

consist of xylem and phloem, and the former is towards the upper surface. A somewhat characteristic layer of cells, the bundle sheath, surrounds the veins. The veins become narrower and narrower until the ultimate branches consist only of one of two vessels, usually with spiral thickening.

The palisade and spongy tissues each have a definite function to perform. The former are exposed to the sunlight and therefore the cells contain many chloroplasts which capture the energy of sunlight. Gases pass through the stomata into the air spaces of the spongy tissue, where also they collect ready to pass out from the leaf through the stomata. The outer walls of the cells in the upper epidermis are usually covered with **cuticle,** so that water vapour does not escape from them to any extent.

5. FLOWERS

In *P. cerasus* and *P. avium* the flowers are arranged in clusters, while in *P. padus* they are arranged along a stem, and less closely clustered than in the others. An arrangement of flowers is called an **inflorescence.**

If a single flower of any species of Cherry be examined its structure is found to be the same. There is an outermost ring of five green leaves, the **sepals.** These form a **calyx,** or cup, and are joined to one another at the base. Inside them, and alternating with them, is a ring of five, larger, white leaves, the **petals.** These form a **corolla,** or crown. Inside these again are numerous yellow boxes on white stalks. These are **stamens,** consisting of an **anther** on a **filament,** and forming the **androecium.** On close inspection the stamens are found to be arranged in three or four rings of ten or five. Those in the outer rings have longer filaments. Each young anther shows two distinct halves. When they are ripe they dehisce, or split open, lengthwise in two places, revealing their contents of fine yellow dust, pollen. The pollen is shed towards the centre

of the flower, the anthers are therefore said to be introrse. The dehisced anthers are very different in appearance. Often those in the outer rings have dehisced while the inner ones remain intact. The filaments of the young inner stamens are sometimes curved over.

In the very centre of the flower is the **pistil,** or **gynaecium.** This consists of three parts, a round, green box, which is the **ovary,** a thin, white stalk-like portion, the **style,** which ends in a flattish disc, the **stigma.** The whole structure really consists of just one small leaf, called a **carpel,** which has become folded round, and of which the tip has elongated to form the style and stigma. If the flower is cut in half lengthwise (Fig. 306), the ovary is seen to be situated at the bottom of a cup, around the rim of which are placed the remaining floral parts. This cup is really a continuation of the flower stalk, or **receptacle.** Because the cup carries the floral parts so that they are around the gynaecium, and rather on the same level as it, the sepals, petals, and stamens are said to be **perigynous** (peri = around: gynous = gynaecium). In the centre of the ovary is seen an oval, white structure, which is the unripe seed or **ovule.**

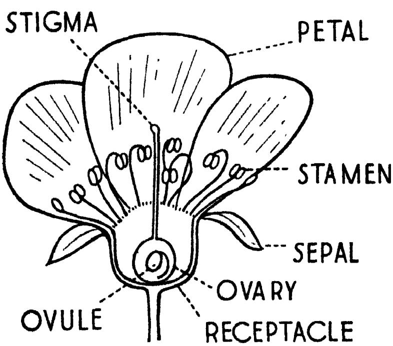


Fig. 306. CHERRY. Half-flower.

Having examined the flower in detail, a little shorthand is a help to collect the result. This is known as a **Floral Formula.** The letter K is used to stand for the Calyx, and the initial letters C, A, and G for the Corolla, Androecium, and Gynaecium respectively. The number placed after

each letter indicates the number of parts of which it is composed; thus K5 means that five sepals make the calyx, A∞ that numerous stamens make the androecium. If it is desired to indicate that the parts, such as the petals or carpels are joined, the number is placed between brackets. Thus K(5) indicates that the five sepals are joined together.

The Cherry flower is quite regular in shape, so that it can be cut into similar halves in several different directions. This is indicated by the sign ⊕ placed at the beginning of the formula. The formula for Cherry flower is therefore ⊕ K(5) C5 A∞ G1.

Now look at the flower with regard to its relation with the main stem, which indicates the posterior, or back, of the flower. The flower comes in the axil of a scale leaf, called a bract, and this comes in the front, or anterior, of the flower. The bract is opposite to a petal, so that a sepal occurs in the posterior position.

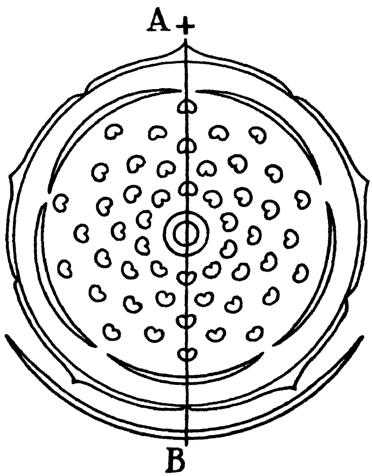


Fig. 307. CHERRY. Floral diagram.

A **floral diagram** shows the positions of all the parts when it is looked down upon from above. In drawing a floral diagram the parts should usually be constructed on circles with the outside one about three inches in diameter. The posterior is indicated by a + and should be placed at the top as in Fig. 307, and the bract opposite to it as shown.

Having found the positions of the petals, these can be placed round a circle inside one which has been left for the

sepals. The circle should be divided into five equal parts, and the usual form is shown in the diagram.

The sepals should then be placed outside. As already stated, the sepals alternate with the petals, that is to say the centre of a sepal comes immediately outside the gap between the edges of two petals. The usual form of the sepal is shown in the diagram.

Inside the petals are the stamens arranged in rings of ten. The form used for a stamen is practically the shape of the anther cut across. As placed in Fig. 307 it indicates that the pollen is shed towards the centre of the flower.

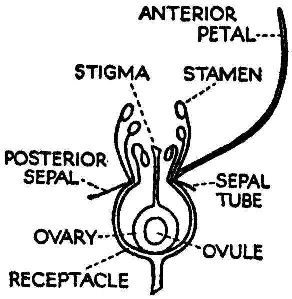


Fig. 308. CHERRY.
Median vertical section.

The gynaecium is in the centre and is represented by a transverse section of the ovary.

Having now written a floral formula and made a floral diagram, we need to have some ideas about the shape of the parts in the vertical direction. To do this a flower should be cut in half in the posterior-anterior, or median, direction, that is, across **A—B** in Fig. 307. In connection with pollination a half-flower is often useful, as shown in Fig. 306. This will show exactly half of the gynaecium, androecium, and corolla. Some of the calyx will be hidden by the corolla.

Sometimes a **median vertical section** is desirable, as shown in Fig. 308, where only the parts actually cut are represented. A section is a thin slice, and a median vertical section is a thin slice out of the centre in the posterior-anterior direction. In the case of the Cherry, it would pass through the centre of the posterior sepal, about three stamens, the pistil, three more stamens, the centre of the anterior petal, and the junction between two anterior sepals.

6. ANTHERS AND OVULES

The ovary of some species of Lily, or of a Tulip, is a convenient one to cut transversely to obtain sections of ovules. Each section will show six ovules, and the ovary is large enough to handle. Sections should be stained (see Appendix) to bring out nuclear details, or prepared slides may be obtained. Ovaries of various ages are needed in order to see ovules in different stages. The **ovules** will be

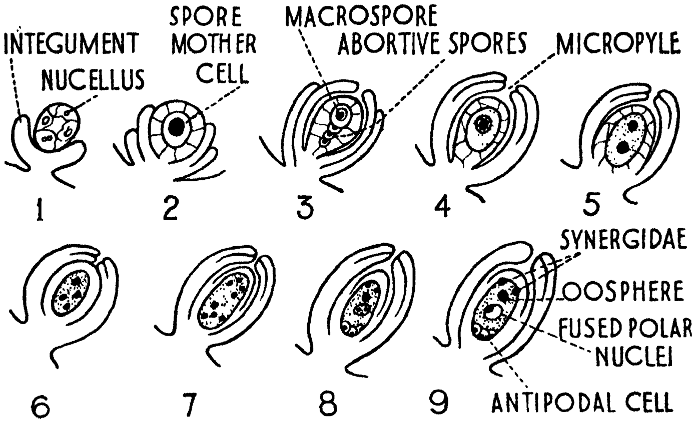


Fig. 309. STAGES IN DEVELOPMENT OF THE OVULE. (Diagrammatic). 4-8 show divisions of the nucleus of the macrospore or embryo sac.

cut longitudinally. Each has a small stalk and two outer coats, or **integuments.** If the section passes through the centre of the ovule a space is revealed in the integuments at the opposite end to the stalk. This is the **micropyle** found in the ripe seed. Enclosed by the integuments is an oval mass of parenchymatous tissue, the **nucellus,** in the centre of which one large cell is prominent (Fig. 309). This is really a **spore mother cell.** It divides by reduction division, just like the spore mother cells in bracken fern

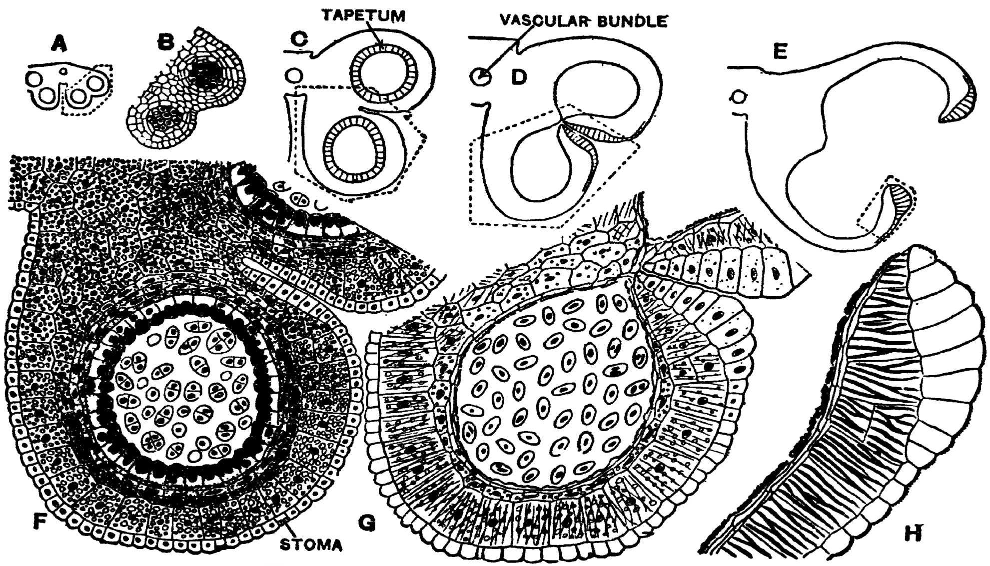


Fig. 310. Structure of Anther of Lily.

(Transverse Sections). A, Young Anther; B, Details of same, showing the Sporogenous Tissue of two of the Pollen-sacs; C, Older Anther; F, Details of same, showing Epidermis, Fibrous Layer (at this stage filled with starch-grains), and Tapetum-layer (large cells) lining the Pollen-sac which contains dividing Pollen-mother-cells; D, Still older (Mature) Anther, just before Dehiscence; note the large size of the Epidermis Cells forming the "Stomium" at the junction of the two Pollen-sacs; G, Details of same: the cells of the Fibrous Layer have lost much of their contents and now show the thickening fibres, and the Tapetum is disorganised, while the Pollen-grains are mature and lie freely in the cavity of the sac; E, Mature Anther after Dehiscence, showing the diverging valves of the Pollen-sac; H, Details of same, showing Fibrous Layer. In all the figures only one half of the Anther is drawn. In A, C, D and E the dotted lines indicate the portions shown more highly magnified in B, F, G and H respectively.

sporangium, into four spores, but only one of these persists and is called the **embryo sac cell.** The nucleus of this divides into two, which move to the opposite ends of the cell. Each of these nuclei divides into four. One from each end then passes to the centre and these two fuse. Cell walls develop around the three nuclei at the end of the sac farthest from the micropyle, and these so-called antipodal cells represent the vegetative cells of a **gametophyte.** Of the three at the micropyle end, one is a **female gamete,** and the other two **synergids,** or help cells. The female gamete now awaits fertilisation by fusion with a male gamete.

The development of an **anther** is shown in Fig. 310. It is two pair of sporangia joined by sterile tissue called the connective. The sporangia contain numerous spores, or **pollen grains,** formed in tetrads by reduction division of spore mother cells. When the stamen becomes dry the cells of the fibrous layer contract causing the stamen to split along two lines. The fibrous layer is a band of thickened cells beneath the outer layer of wall cells of each sporangium. The split occurs between two sporangia. Stamens of Lily, or Tulip, again provide possible material from which to cut sections. The pollen grains produce the male gametes, but these must be conveyed by some means or other to the ovules. For this purpose the pollen grains themselves are conveyed to the stigma.

7. POLLINATION

Since the stigma is above the level of the stamens (Fig. 306) the pollen must be conveyed by some external agent, in this case, an insect. Thus the flower must provide some attraction for insects. It calls their attention by the showy petals, but they would not visit it unless it provided food. The inside of the receptacle produces a sweet juice called nectar, which the insects take, and for which they unconsciously pay. An insect visiting a flower

stands on the stamens so that its legs and the under surface of its body become dusted with pollen. When it visits another flower it first touches the stigma, thus depositing on it some pollen. In this way it carries pollen from one flower to another, that is, causes **cross-pollination.** True cross-pollination occurs when the flowers are growing on two different trees, and is advantageous, as explained in connection with Chlamydomonas in Chapter I. As Cherry blooms in March when few insects are about, the pollinating insect is often a bee; but the flower may be visited by smaller insects of the fly type, since they too would be able to reach the nectar.

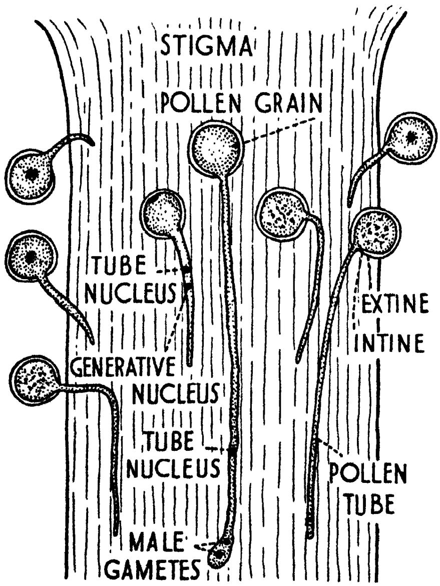


Fig. 311. Germinating Pollen-Grains.

Having reached the stigma, the **pollen grains** proceed to develop. Each possesses two coats, extine and intine, and one nucleus. This divides into two and the grain contains two cells, a **generative cell** and a **tube cell** (Fig. 311). The tube cell starts to grow out and a tube is formed, which grows down the style into the ovary (Fig. 312) and enters the micropyle of an ovule. In Cherry only one **pollen tube** is needed since there is only one ovule, but ovaries containing many ovules need many pollen tubes. The generative

and tube cell nuclei pass to the tip of the tube, but the former has by now divided into two **male gametes.** The pollen tube grows through the nucellus and touches the embryo sac. The synergids become mucilaginous and this causes the embryo sac wall and the tip of the tube to burst. The two gametes enter the embryo sac, the tube cell nucleus having by this time disintegrated. **Fertilisation** occurs when one of them fuses with the female gamete, forming an oospore, and the second passes further in and fuses with the already double nucleus in the middle of the sac, giving **triple fusion.** The fusion of the male and female gamete merely restores the number of chromosomes present in all except the gametophyte cells, but the triple fusion nucleus is a " freak " one.

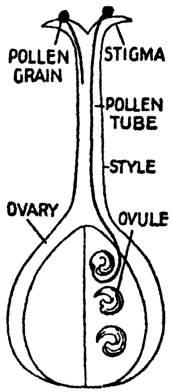


Fig. 312. The Growth of Pollen-Tubes.

8. DEVELOPMENT OF EMBRYO

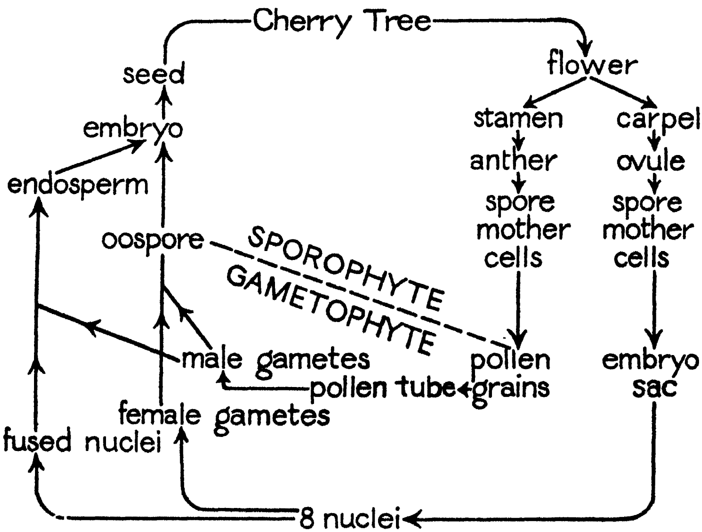
The triple fusion nucleus proceeds to divide rapidly, forming so much tissue that the nucellus is gradually crushed out of existence. The new tissue thus formed is called **endosperm,** and becomes packed with food supplies.

The oospore develops into the embryo. This development can be followed in ovules of the very common weed, Shepherd's Purse. They can be mounted whole, and by gently pressing on the cover glass, can be burst so that the embryos escape. The oospore first divides into two cells, that nearer the micropyle being called the upper cell (Fig. 313). This cell divides into a row of cells called the **suspensor;** the one at the upper end being much larger than the others. This cell is called the **embryo cell,** and the suspensor pushes it into the endosperm. The embryo cell divides into eight cells called octants. Four are shown

in Fig. 313, the other four are behind them. From the four octants nearest the suspensor are developed part of the growing point of the radicle, and the hypocotyl, that is part of the axis immediately beneath the cotyledons. The adjoining cell of the suspensor takes part in the formation of the radicle. From the other four octants the growing points of the plumule and the two cotyledons are derived.

In Cherry, Bean and Pea, by the time the embryo has fully developed it has used up all the endosperm, so that the ripe seed contains only the embryo as already seen. Such a seed is called **non-endospermous,** but sometimes some of the endosperm remains, giving an endospermous seed, as described in Chapters XIX. and XX. The integuments of the ovule form the testa of the seed.

The life cycle of Cherry and indeed of any flowering plant may be summed up as follows:—



The sporophyte and gametophyte generations are present and alternate with one another, but the gametophyte is

very much suppressed, practically consisting only of the actual gametes. All the cells in the gametophyte have only *n* chromosomes as compared with 2*n* in the sporophyte.

9. FRUIT

During the time when the embryo has been developing, changes have been occurring in the ovary leading to the formation of the fruit. After pollination all the parts of the flower wither and fall off except the ovary, which increases in size. There are three layers to the carpel,

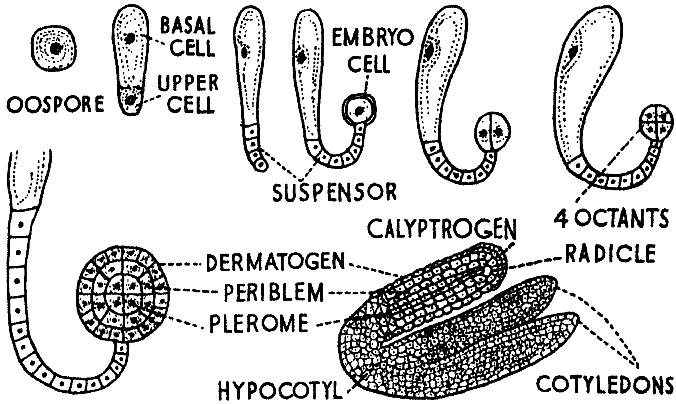


Fig. 313. DICOTYLEDON EMBRYO.
Diagrammatic representation of some stages in development.

and each of these acquires a distinctive character. The innermost one, the **endocarp**, becomes hard and forms the Cherry stone. The middle one increases greatly in thickness and becomes juicy and succulent. This is the **mesocarp**; while the outer layer, which is only a thin skin, constitutes the **epicarp**. These parts are shown in Fig. 314, which also shows the testa of the seed and the stalk by which the seed is attached to the endocarp. This type of succulent fruit, consisting of one carpel, containing one seed, and possessing

a stony layer, is called a **drupe.** By the time the fruit is ripe the green skin has become either red or black. A line passing down one side of the skin (Fig. 314) reveals where the edges of the carpel have united, and a black dot opposite to the stalk indicates where the style was attached.

A plant has fruits in order that there may be new plants, and for this purpose the seeds must be shed from the plant. If all fell beneath the parent tree, when the seedlings grew, they would deprive one another of food, air, and light. In other words there would be too much competition amongst them. They would also be very badly shaded by the parent tree. This indicates that it is an advantage if the fruits can be carried by some means away from the parent plant. Cherry fruit is adapted for this to happen by being edible. When we eat cherries we often throw away the stones where they may germinate. Succulent fruits are often dispersed by birds, which they attract by their bright colours. A bird may deliberately throw out the hard seeds or may swallow them. In the latter case they are protected from digestive juices by a hard covering, and pass out of the bird's body unharmed, thus landing a good distance from the parent plant, and most probably somewhere where they can germinate. Birds feed eagerly on fruits of wild rose and hawthorn, and on currants if allowed to do so. Many other hedgerow plants have succulent fruits of which birds scatter the seed.

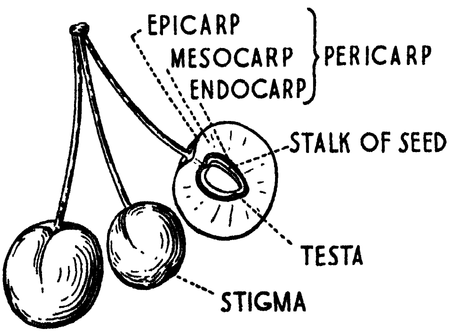


Fig. 314. CHERRY FRUITS.

CHAPTER XIX

MONOCOTYLEDONS

1. INTRODUCTORY

Plants which bear flowers are divided into two large classes, Dicotyledons and Monocotyledons. The names have been derived from their seed structure, but they represent two very distinct types of growth. The Cherry tree is one typical dicotyledon form; we will now consider some monocotyledon characters.

2. LILIUM

Lilium is a genus with which you are familiar to some extent. It comprises the various species of Madonna and Tiger Lilies. These plants, like a Cherry tree, are perennial but all, or practically all, the aerial part dies down each year, and the new growth comes up from an underground part, known as a bulb. The amount of growth is consequently

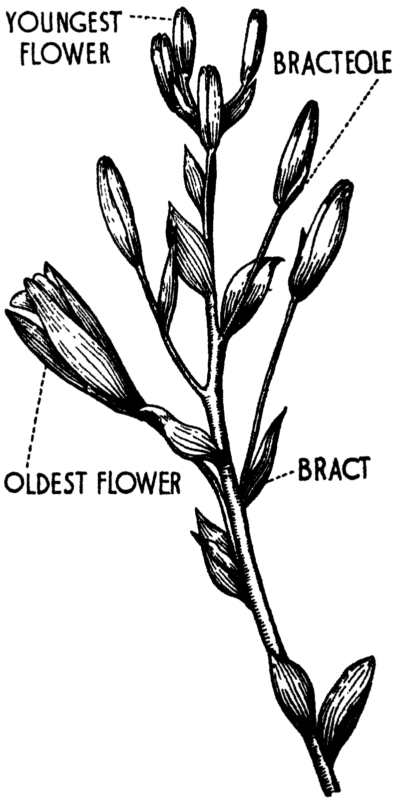


Fig. 315. LILY INFLORESCENCE.

limited, it cannot go on increasing indefinitely year after year, as that of a Cherry tree can. Plants of this kind therefore do not become woody and are called **herbaceous.**

The aerial part of *Lilium* consists of a stem, bearing leaves, and at the tip, flowers (Fig. 315). The **leaves** arise alternately on the stem, they are very simple in outline and have no petiole, but their base wraps round the stem. These leaves have many veins, which traverse the whole, or nearly the whole, of their length, and do not make a network by joining with one another. Veining of this type is said to be **parallel** (Fig. 316), and is characteristic of monocotyledons. Microscopic examination of the epidermis, and a transverse section of the leaf shows features essentially similar to those of Cherry leaf, except that the palisade mesophyll is much less defined, and the vascular bundles are rather different, as will be seen in connection with the stem.

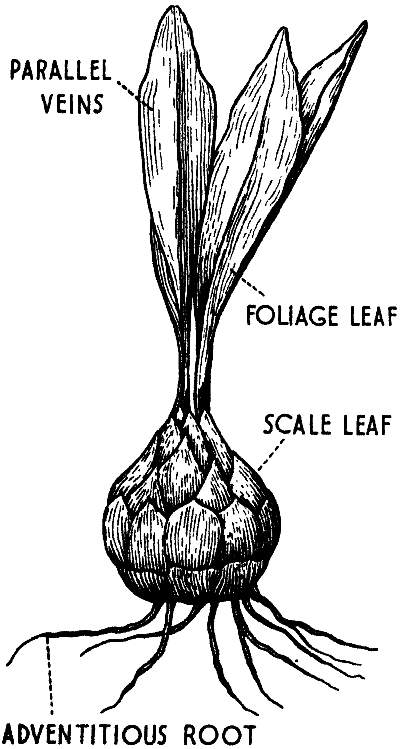


Fig. 316. Lily Bulb.

If a transverse section of the **stem** be cut, it is seen to have a considerable number of vascular bundles scattered

all over it (Fig. 317). When examined individually each bundle is seen to have xylem and phloem only (Fig. 318), no cambium, and therefore no power of secondary growth. A very large number of bundles enter the stem from each leaf. Those at the middle of the leaf pass inwards to the centre of the stem, while those nearer the margin of the leaf do not travel so far inwards (Fig. 319). The central bundles follow an oblique path towards the edge of the stem, so that nearer the outside there are many more bundles than in the centre, while the latter are often the largest. The elements which compose the vascular bundle are similar to those in a dicotyledon. The protoxylem consists of spiral vessels; whilst those formed later are pitted. The latter are usually distinctly larger. A good deal of xylem parenchyma usually remains. The phloem consists of sieve-tubes and companion cells. In grasses and

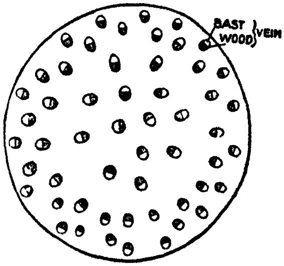


Fig. 317. TULIP STEM.

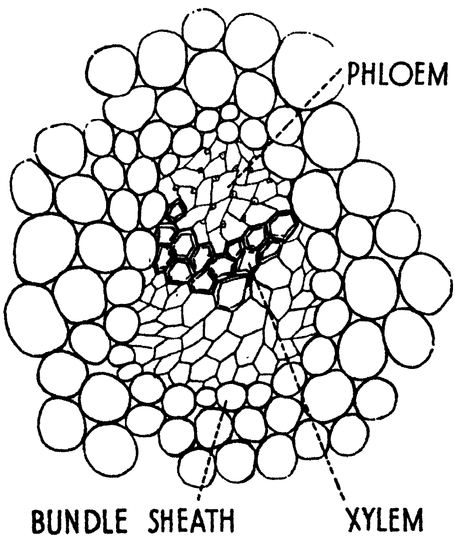


Fig. 318. LILY STEM.
Transverse section of Vascular Bundle.

cereals the bundles have a characteristic form (Fig. 320). Here an annular vessel usually follows a spiral one. Owing to rapid elongation an air cavity is formed by the separation of cell walls, therefore said to be lysigenous in origin. The two larger vessels are pitted and form a little hollow between them, in which the phloem occurs. The cells immediately round the bundles are always very regularly placed and make a bundle sheath, which may become sclerenchyma. There is no distinct pith, but strengthening tissue sometimes occurs in the small cortex, as it may also do in dicotyledons. The whole is covered by an epidermis. Many monocotyledon stems remain green, in which case immediately beneath the epidermis are a number of parenchyma cells containing chloroplasts.

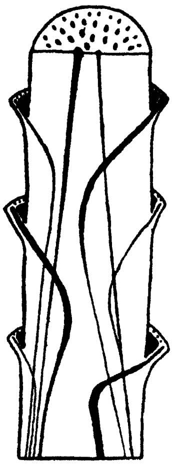


Fig. 319. MONOCOTYLEDON. Longitudinal course of the bundles. (Diagrammatic.)

Near the tip of the stem, the leaves become modified somewhat, have flower buds in their axils, that is, in the angles made by them with the stem, and are therefore called **bracts.** The flowers have a small stalk, and they gradually get younger towards the tip of the stem, which, for a time, continues to grow (Fig. 315). This type of growth with flower arrangement is called a **raceme.**

The flower has six attractive "petals." These, when examined carefully, are seen to be three outer and three inner, which in many species are joined together at the base to make a short tube. The petaloid members make a **perianth,** and each is a perianth leaf. At their base **nectar** is secreted for feeding insects, which are attracted by the colour and scent, and guided often by lines and marks of different colour on them. Inside the perianth there are 3 + 3 **stamens,**

making the **androecium** (Fig. 321). The filaments are usually attached to the perianth leaves, *i.e.* epiphyllous. The anther is large and is attached to the filament about in the middle of its long side, so that it swings on it like a see-saw. This method of attachment is spoken of as versatile. The insect, in collecting the nectar, touches the anther and causes it to swing, thus shaking out the pollen. The three outer stamens shed their pollen before the three inner. All the stamens ripen before the stigma, and

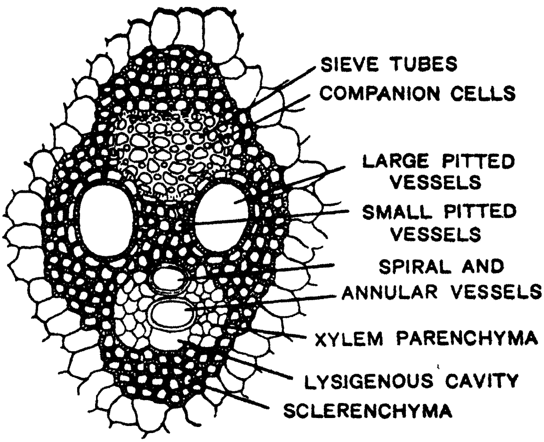


Fig. 320. MAIZE.
Transverse section of vascular bundle.

the flower is therefore called **protandrous.** The **gynaecium** consists of three joined carpels and is **superior.** The three stigmas are clearly visible at the top of a long style, and the ovary, if cut across, shows three compartments, each with two longitudinal rows of ovules, fastened at the centre of the gynaecium, so that their placentation is **axile** (Fig. 322). The flower is quite regular in form and arrangement, that is, it is **actinomorphic.** As the ovary is superior, the other flower parts arise below the gynaecium,

and are therefore said to be **hypogynous.** The formula is:—

$$\oplus \{P3+3\ A3+3\}\ G(\underline{3}).$$

or it may be:—

$$\oplus \{(P3+3)\ A3+3\}\ G(\underline{3}).$$

The line beneath the number of carpels indicates that the ovary is superior, and the brackets { } that the stamens are epiphyllous. It will have been noticed that all the parts are in threes, which is the characteristic number for monocotyledonous flower parts.

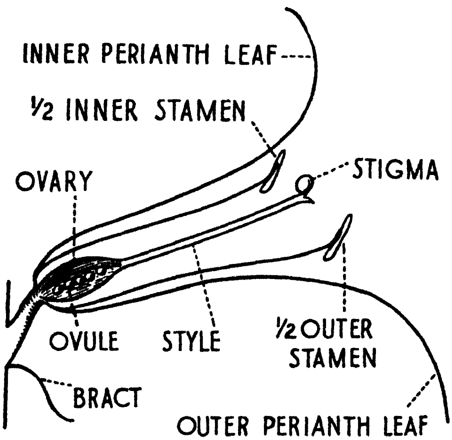


Fig. 321. LILY.
Median vertical section.

After pollination and fertilisation the **fruit** develops, and when ripe, becomes brown and dry, each carpel dehiscing longitudinally to allow the seeds to come out, as the fruit is swayed about by the bending of the stem in response to the wind (Fig. 323).

The **seeds** are rather small for examination, so that the parts would be much more easily seen in a maize or wheat grain. They should, in any case, be soaked for about twelve hours, so that they are soft. One **maize grain** is the entire product of one flower; it is a one seeded fruit. Cereals and grasses have the unusual character of the pericarp and testa being fused together so that they cannot be separated. At one end of the grain is the stalk; in the centre of the opposite end the remains of the stigma can be seen. On

one of the broad sides the embryo can be seen through the covering (Fig. 334). This embryo has a radicle, plumule, and one cotyledon, a large part of the seed being made of an extra tissue containing stored food, and known as **endosperm.** The latter is always rather different in colour from the embryo. The parts are well seen if the grain be cut in half, along the radicle and plumule line. With the help of a hand lens, the following parts can be observed:—the root with its root-cap; the hypocotyl with the cotyledon stalk attached to the axis immediately above it; the stem with its tip enclosed in a number of sheathing leaves (Fig. 324).

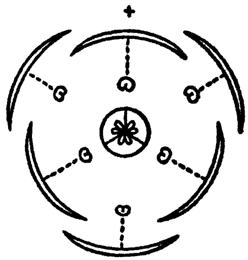


Fig. 322. LILY. Floral diagram.

The edge of the cotyledon (also here called a scutellum because it is shield-like) which borders the endosperm is a special digestive layer. The food in the endosperm is chiefly starch, while the cotyledon contains sugar, produced by the action upon this of an enzyme, called diastase. The edge of the endosperm nearest the testa, known as the aleurone layer, contains protein, in the form of

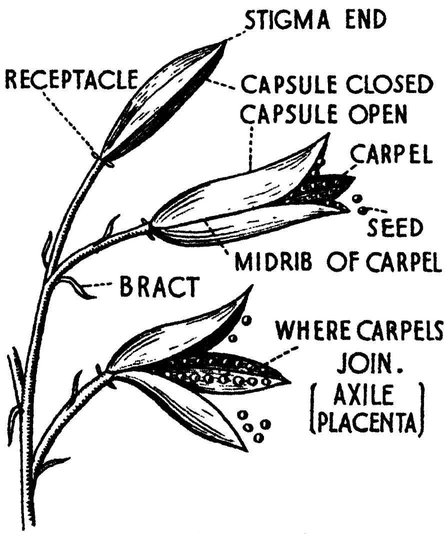


Fig. 323. FRUIT OF LILY.

aleurone grains (see Chapter XXIII.), and oil. Exactly similar parts will be found in a wheat grain, if it be cut in the right direction. A grain of polished rice consists only of the starchy part of the endosperm, the mark where the embryo has been removed being quite clear. The parts will vary in shape and relative size, but they are typical of the monocotyledonous seed.

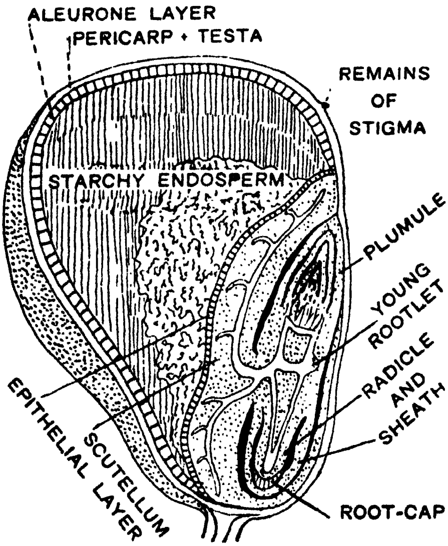


Fig. 324. Maize.
Fruit cut longitudinally.

Beneath the surface of the soil, the Lily plant has a **bulb** (Fig. 326). The bulb consists of a number of **scale leaves** attached to a small piece of **stem.** The scale leaves are thick and fleshy, because they contain a food store for the development of the aerial part of the plant. Some of these scale leaves are the bases of foliage leaves, which formed a circle round the base of the aerial stem. If a longitudinal section of the bulb be cut it will be seen that new food leaves are formed each year within the old, which have gradually become thin and shrivelled as their food has been used. The aerial stem arises as a branch on the main stem of the bulb in the axil of one of the innermost leaves. Sometimes a new bulb arises as a bud in the axil of one of the

outer scale leaves. From the stem of the bulbs **roots** grow, which, because they arise on a stem, are said to be **adventitious.** When planting Lilies in our gardens, we plant bulbs, not seeds. The former have a much larger food store and a large bud in the centre, from which the aerial shoot with its flowers develops, and consequently it can grow much more quickly than the little plant from the seed. This is known as **vegetative reproduction,** because the bulb consists of stem and leaves, which are vegetative parts. If a seed of Lilium is planted, several years elapse before the resulting plant becomes large and strong enough to bear flowers.

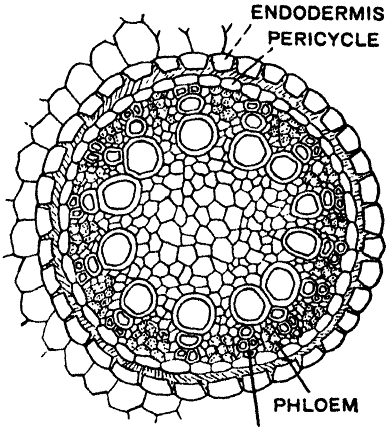


Fig. 325. LILY.
Transverse section of the central part of the root, showing the polyarch stele.

The **roots** of Lilium have a root-cap and root-hairs like the roots of the Cherry tree. Corresponding parts exist at the growing point. A transverse section exhibits the parts shown in Fig. 325. These parts agree with those of the young Cherry roots, except in numbers. There are many more groups of protoxylem; thus the area of the stele is increased, and many more cells in the centre remain as parenchyma.

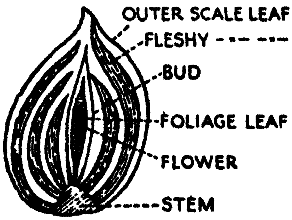


Fig. 326. TULIP.
Longitudinal section of bulb.

These roots do not usually live for more than one year, so there is no need for secondary growth.

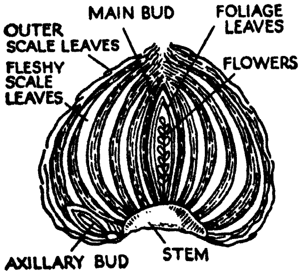


Fig. 327. HYACINTH.
Longitudinal section of bulb.

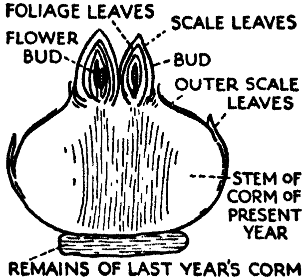


Fig. 328. CROCUS.
Longitudinal section of corm.

3. OTHER MONOCOTYLEDONS

Many of our spring flowers have characters greatly resembling those described above for Lilium. Thus Tulips have similar stem and foliage, the flower parts agree exactly with those of Lilies, the fruit and seed are similar, and they reproduce vegetatively by **bulbs.** The scale leaves of the latter fit much more closely together than those of Lilium, some of them wrapping completely round the others (Fig. 326). For this reason the Tulip bulbs are said to be **tunicated**, and those of the Lily **scaly.** Other examples of tunicated bulbs are seen in Narcissus, Hyacinth, Onion (Fig. 327), and many others, where all the leaves more definitely still wrap round the inner parts. Here it is easy to see that each resting bulb contains parts belonging to three seasons:—the bud for the next season's

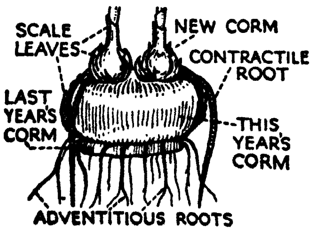


Fig. 329. CROCUS CORM.

development; the food storing leaves, which are the bases of the previous season's foliage leaves; the outer protective wrappings, which in the previous season were fleshy, and were therefore bases of the foliage the year before. The foliage leaves in these cases are attached to the stem in the bulb and come straight out of the ground; there is no aerial, leafy stem.

Some plants like Crocus, Gladiolus, Montbretia have **corms** instead of bulbs. In these the scale leaves are only protective, the food is stored in a short, thick piece of stem, on the top of which develop one or more buds from which the leaves and flowers arise (Fig. 328). The base of the aerial shoot becomes the new corm for the next year. Here the need for **contractile roots** (Fig. 329), to pull the new growth down to prevent the plant from working out of the soil, is more apparent than in the case of bulbs. A contractile root is a thick root which grows straight down into the soil, holds on very firmly by its root hairs, and then contracts, pulling the plant down as it does so. The contraction causes the surface to become wrinkled.

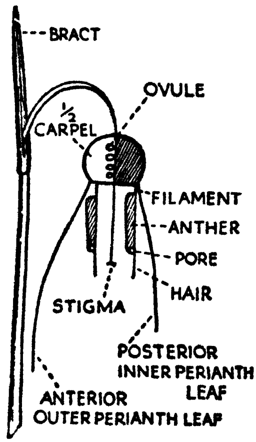


Fig. 330. Snowdrop. Median vertical section.

If flowers of **Tulips, Hyacinths,** and **Bluebells** be examined, they will be found to have the same number and arrangement of parts. If, however, flowers of the genus **Narcissus** and **Snowdrop** (*Galanthus*) be examined the position of the ovary will be found to be quite different. It is beneath the origin of the perianth leaves, that is, the ovary is inferior (Fig. 330). This is indicated in the floral formula by placing the line on top of the number of carpels, thus

$G(\bar{3})$. This condition has arisen by the receptacle, which had grown round the ovary to make the calyx, corolla, and androecium perigynous in Cherry, having grown right up

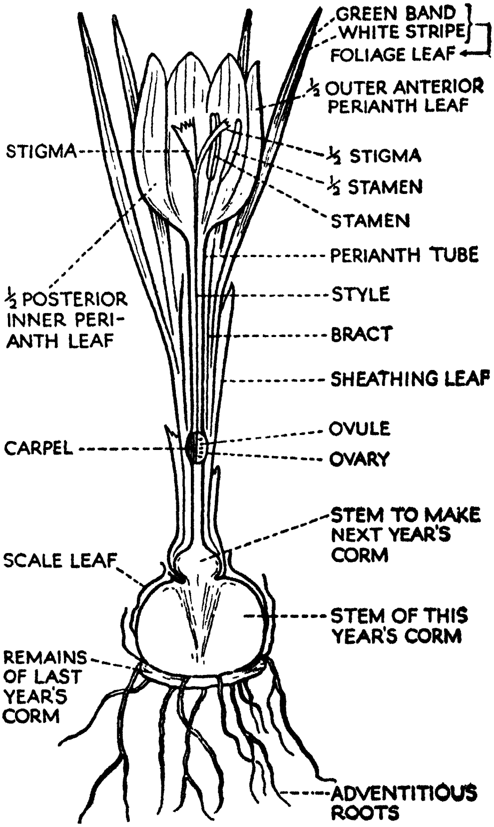


Fig. 331. Crocus.
Half-Plant.

above the ovary and in close contact with it so that they cannot be separated. The perianth is now **epigynous**, that is, above the ovary. In the genus Narcissus the perianth

leaves have three parts, one which makes the tube and one the trumpet or corona, and a third which spreads out like a free petal where the other two join. The stamens of Snowdrop are interesting, because they open by two pores at the top and the connective is continued into a slender hair. The flower is pendulous and visited by bees. The hair touches the insect's head whilst it collects nectar and causes the anther to be shaken, so that the pollen comes out like pepper out of a pepper pot.

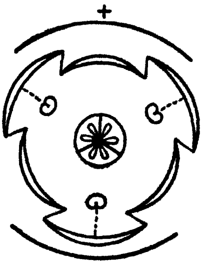


Fig. 332. IRIS. Floral diagram.

In **Crocus, Montbretia** and **Gladiolus** only three stamens are present. The stigmas are rather large, and the ovary is inferior, in Crocus beneath a very long, narrow perianth tube (Fig. 331). The three stamens represent the three

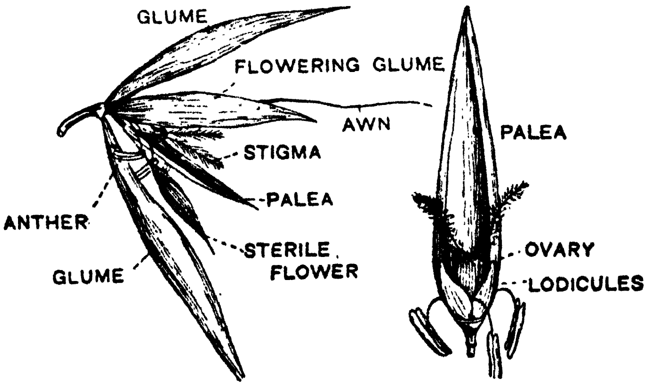


Fig. 333. OAT.
Spikelet and flower. In the second figure the flowering glume has been removed.

outer stamens of the other flower, the three inner having been suppressed. This is shown by their position and

that of the carpels (Fig. 332). Grasses and cereals have flowers which are pollinated by the wind, that is, they are anemophilous. Many grasses in the summer time send up long stalks, bearing at their tips numerous small flowers, which are only rendered at all conspicuous by the relatively large anthers, which may be yellow, blue, red, or mauve, and protrude from them. There are three stamens to each little flower or floret (Fig. 333), with versatile anthers which are very easily swayed by the wind. The single carpel has only one ovule in its ovary, but two feathery stigmas to give large surface of a suitable kind to catch wind-borne pollen grains. The androecium and gynaecium are protected by a number of rather special scales called glumes and paleae, which become parted to some extent by the movement of two very small structures, called lodicules, which are a rudimentary perianth. Although small they help the anthers and stigmas to emerge. There is no need for an attractive perianth or nectar in an anemophilous flower, consequently there is reduction of these parts.

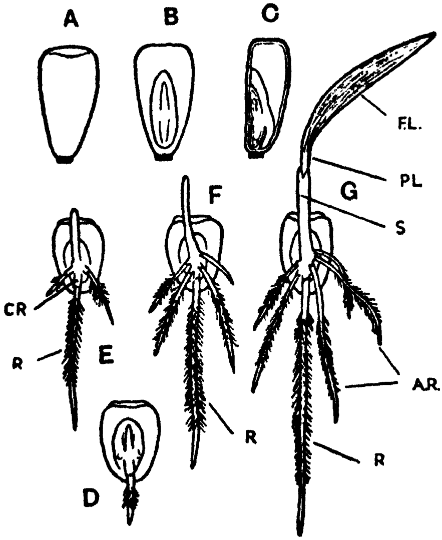


Fig. 334. Germination of Maize.
A, B, Fruit in surface view; C, Fruit in section; D-G, Stages in development of seedling; CR, Radicle sheath; R, Radicle; AR, Adventitious root; S, Plumule sheath; PL, Plumule; FL, Foliage leaf.

Some seeds of monocotyledons should be sown to watch their germination. This will be found to be essentially of two types, which are well seen in Maize and Onion.

The **Maize grains** absorb water and swell, then the radicle breaks through the testa and pericarp and grows down into the soil. Later the plumule also breaks through, enclosed in a straight tubular sheath (Fig. 334). The root shows very good root-cap and root hairs. After a while the green leaf bursts the sheath which protected the plumule as it pushed its way through the soil. By this time roots will be seen developing from the base of the stem, not from the radicle. These are therefore adventitious and they develop quickly so that they soon grow more than the radicle.

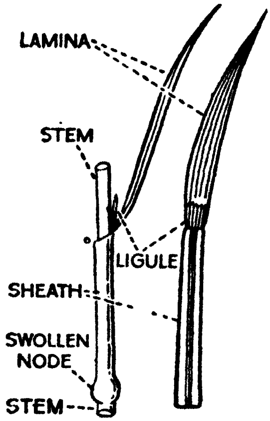


Fig. 335. Grass Leaves.

In **Oats** these roots emerge from the opposite end of the grain to the radicle. The roots are thin and spread rather horizontally. The root system is therefore fibrous as well as adventitious. As the little plant grows, roots develop from the hypocotyl and stem base, and grow out at angles, thus serving to help the plant to stand erect; they are therefore called prop roots.

In Maize, as in all grasses, the leaf is characterised by having three distinct parts:—a long sheathing base, the lamina, and where these two meet, a ligule (Fig. 335). The ligule is a small sheathing piece which stands up round the stem, making a little gutter, so that rain collected by the lamina does not enter between the leaf sheath and stem, but flows outside to the soil where the roots are. Typical grass stems have swollen nodes.

The **Onion** behaves quite differently. After the root has made its way a short distance into the soil, a hooked thin, green structure emerges from the soil, bringing the seed coat with it (Fig. 336). This is the cotyledon, which is epigeal (Gk. *epi* = above, *geos* = earth), not hypogeal (Gk. *hypo* = beneath), as in the Maize. For some time the tip of the cotyledon remains buried in the testa, where there is also endosperm, which the cotyledon is digesting. After a time the first foliage leaf appears. Very early in the life of this little plant the bulb begins to form.

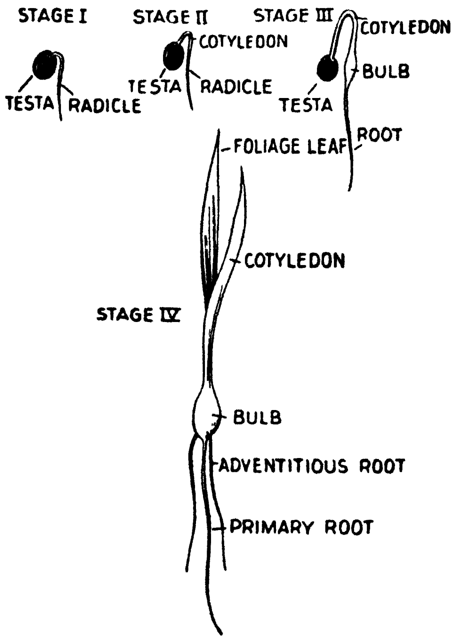


Fig. 336. Onion Seedling.
Stages in the development.

Seedling plants of Bluebells, *Scilla nutans*, are quite common in the woods with small bulbs developing.

The majority of British monocotyledons are herbaceous plants, but Palms, Bamboo, Sugarcane, Aloes, and Agaves are more or less familiar amongst the larger Monocotyledons of warmer climates.

CHAPTER XX

SOME HERBACEOUS DICOTYLEDONS

1. INTRODUCTORY

In addition to the trees of our woodlands and shrubs of our hedges, dicotyledons play a very large part in our herbaceous flora and also in plants grown for fruit and vegetables.

Having studied the Cherry tree and monocotyledons, it will be easy to recognise dicotyledons from their foliage and general habits of growth.

2. BUTTERCUP (*Ranunculus*)

Let us now examine some common herbaceous dicotyledons. There are several common species of Ranunculus:

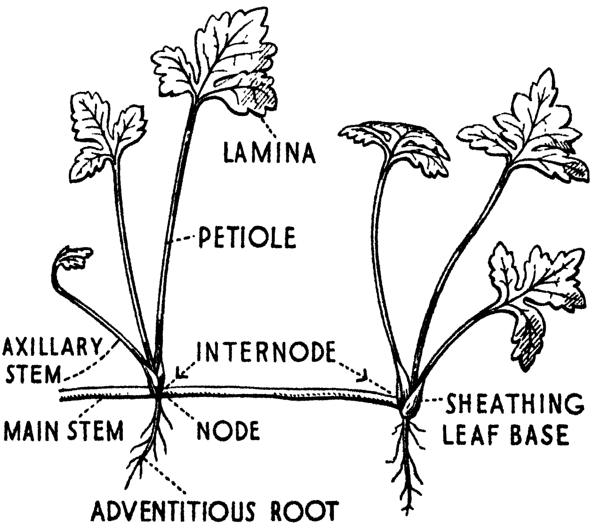


Fig. 337. BUTTERCUP WITH CREEPING STEM.

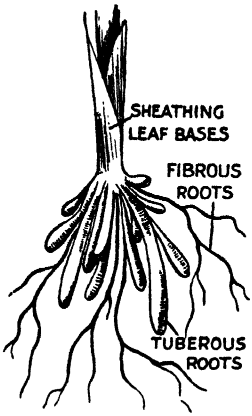


Fig. 338. LESSER CELANDINE.

Ranunculus bulbosus, which has a corm, and is common in meadows and waste places; *Ranunculus repens*, also common on waste ground, has a **creeping stem**, that is, instead of standing erect it lies along the ground, and roots at almost every node (Fig. 337), thus providing a means of vegetative reproduction; *Ranunculus ficaria*, commonly known as Lesser Celandine, which has some swollen roots full of food, by means of which it multiplies and lives through the winter; they are called **tuberous roots** (Fig. 338); and *Ranunculus aquatilis*, which grows in ponds and streams.

The leaves of Ranunculus are simple, often with the margin very much indented. The leaf base is sheathing. The veins are palmate net, because several principal veins meet at the top of the petiole, and round each of these a network is formed (Fig. 337). Where there is more than one main vein it is compared with the hand, with its fingers, hence the term **palmate.** *Ranunculus aquatilis*, sometimes called Water Crowfoot, has two kinds of leaves; those which are submerged in the water and those which float. The former are very much divided (Fig. 339), a condition which provides large surface for absorption of substances from the water, and, at the same time, offers very little resistance to the movement of the water. The floating

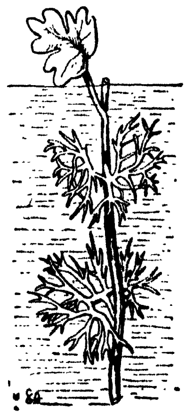


Fig. 339. PART OF A WATER CROWFOOT. Showing a floating leaf and two submerged leaves.

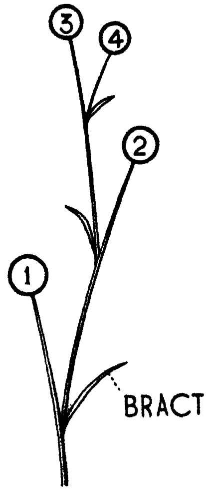


Fig. 340.
BUTTERCUP.
Plan of inflorescence.

leaves resemble somewhat those of *Ranunculus ficaria*, the margins of which also are not indented. In *Ranunculus aquatilis* the upper surface is covered with wax because the stomata are on this side, and it is therefore essential that the surface does not remain wet and the pores get blocked.

In Buttercup the main stem ends in the oldest flower; the next arises in the axil of the uppermost leaf or bract, and the next as a branch on the first branch, and so on. This type of inflorescence is called a **cyme**, and when only one branch arises at one node, it is a **monochasium**, or one-sided cyme (Fig. 340). Where two branches arise at one node it is a **dichasium**, or two-sided cyme. A cyme is an example of sympodial growth since the main stem and the branches soon have their growth ended by a flower.

In the flower of Buttercup all the parts are free, the

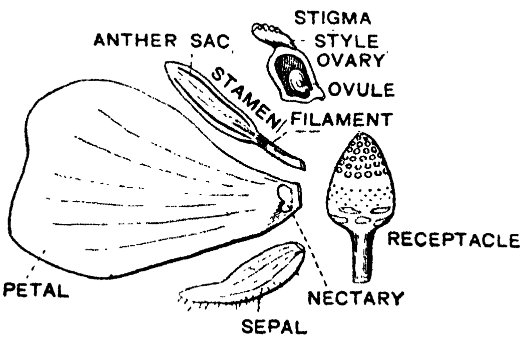


Fig. 341. BUTTERCUP.
Parts of flower; the points of insertion of the different parts are diagrammatically represented on the receptacle.

sepals, petals, and stamens are hypogynous and the carpels are superior (Fig. 341). The two species *Ranunculus bulbosus* and *Ranunculus repens* may be readily distinguished from one another by their vegetative characters, as already explained. In addition to these differences, the sepals of *Ranunculus bulbosus* are turned back, helping us to distinguish between the flowers. The number of stamens and carpels is large, said to be indefinite, and they are arranged spirally round the receptacle (Fig. 342), which just continues to elongate as much as necessary to accommodate all the parts. The floral formula is—

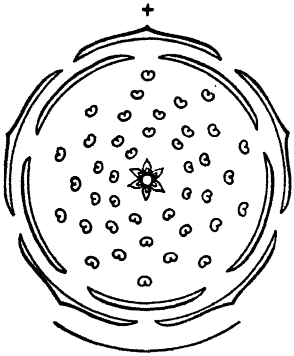


Fig. 342. BUTTERCUP. Floral diagram.

$$\oplus\ K5\ C5\ A\infty\ \underline{G\infty}.$$

The petals each have a nectary at their base (Fig. 343). The stamens open towards the petals, that is, they are **extrorse**, so that pollen does not fall on to the stigmas and cause self-pollination; see Chapter XVIII. While collecting nectar the insect also gathers pollen on its body. The carpels are small and each contains one ovule. When the carpels are free from one another, the gynaecium is said to be **apocarpous.** The fruit of Buttercup is compound, because it is made by a number of separate pieces. Each carpel becomes dry and does not open to let the seed out; the fruit each makes is called an **achene.**

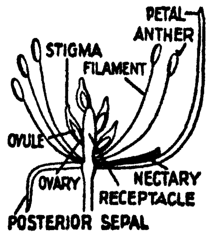


Fig. 343. BUTTERCUP. Median vertical section.

3. STRAWBERRY

Strawberry (*Fragraria*) has a vertical underground stem. Numerous leaves spirally arranged occur very close together on this stem. They arise from the soil, giving the impression that they are growing from the root, and hence are said to be arranged radically. It produces long axillary stems which trail on the ground, and each forms a bud at the tip. These buds root and develop into new plants. The branches are called **runners** (Fig. 344), and they bring about vegetative reproduction of the plant.

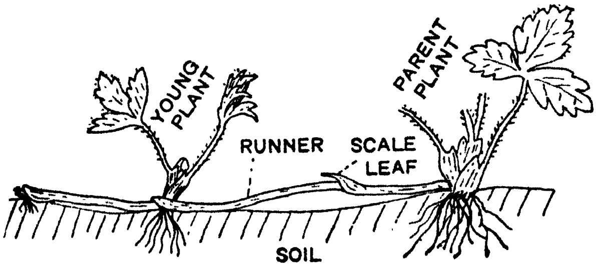


Fig. 344. RUNNER OF STRAWBERRY.

This plant has **compound leaves**, which are derived from a leaf with **palmate** net veins. In Buttercup the margin was very deeply cut, in Strawberry the lamina has been cut right to the petiole so that there are three separate pieces. These are called leaflets, and each has pinnate net veins. Strawberry leaves also have two small, wing-like appendages at the base of the petiole, known as **stipules.** These small appendages have a protective function while the parts are small and young.

4. BEAN AND PEA

Runner Bean, *Phaseolus,* and Broad Bean, *Vicia Faba,* are two very common beans, some part of which is familiar to everyone. The former is a plant which **climbs** by means

of its stem, which it twines round any suitable support (Fig. 345). This plant grows long internodes quickly so that the tip transcribes a larger circle than usual, which is a great help in finding, and getting round, a support. The stem naturally grows erect, so the support must not be too obliquely placed or the stem will not be able to keep hold of it. The climbing habit is a very economical one, as there is no need for much development of strengthening tissue, and consequently the energy saved can be used to grow tall quickly, thus obtaining a good position for getting light, and later for pollination and seed dispersal. The leaves in the seedling of Runner Bean are simple, but in the adult are compound. At the base of the petiole and also at the base of each leaflet, there is a swelling (Fig. 345) called a **pulvinus.** It is this swollen part which enables the leaf to droop at night and assume a horizontal position in the daytime. Some leaves which have pulvini have very marked rhythmical movements, *e.g.* Clover, in which the leaflets fold up at night in a characteristic way to reduce the surface exposed.

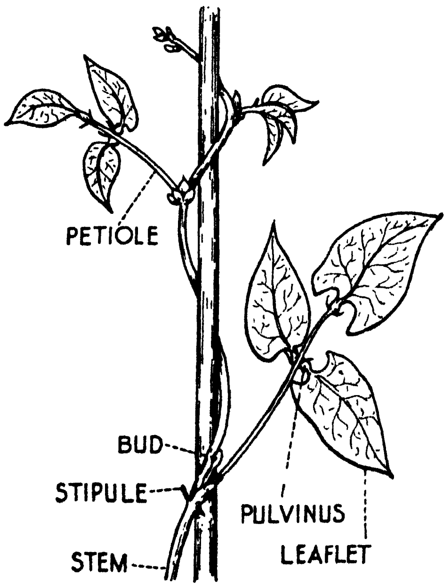


Fig. 345. Runner Bean with Twining Stem.

Broad Beans are short, erect plants with square stems. They have **compound pinnate** leaves, that is, they have been derived from a simple lamina with pinnate net veins, which has become divided along two of the secondary veins to make two leaflets. The end of the midrib forms a rudimentary climbing organ. The leaf also has a pair of prominent **stipules**, which have the other leaf parts folded within them when in the bud.

There are two well-known genera of **Pea.** The edible Pea is *Pisum sativum*, the fragrant Sweet Pea and the Everlasting Pea are two species of *Lathyrus*. The Sweet Pea and edible Pea are examples of species with very many varieties, observable in the different colouring of the blossoms of the one, and in the difference in the pod and flavour of the seeds in the other.

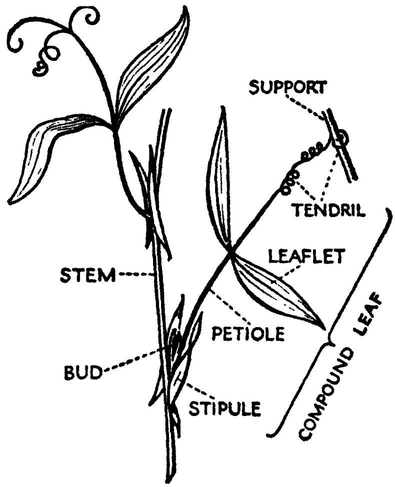


Fig. 346. LEAF OF MEADOW PEA.

There are several wild species of Lathyrus, the commonest being *Lathyrus pratensis*, the Meadow Pea. This has racemes of yellow flowers, and may be found in flower in the hedges in early summer.

In Peas the terminal leaflets are modified to make climbing organs known as **tendrils** (Fig. 346). A tendril is long and thin, and has a curved tip, which is sensitive to contact. If it touches some solid support, not too large or too smooth, it holds on to it, gradually curving round it. After it has become firmly attached it twists spirally

between the point of attachment and its origin on the petiole. Since the spiral is produced in a part fixed at both ends it must be a double spiral (Fig. 346). The spiral curvature serves to draw the plant up a little, and it also provides a very great deal of elasticity, and therefore strength, since it will no longer be easily snapped by the wind or passing animal.

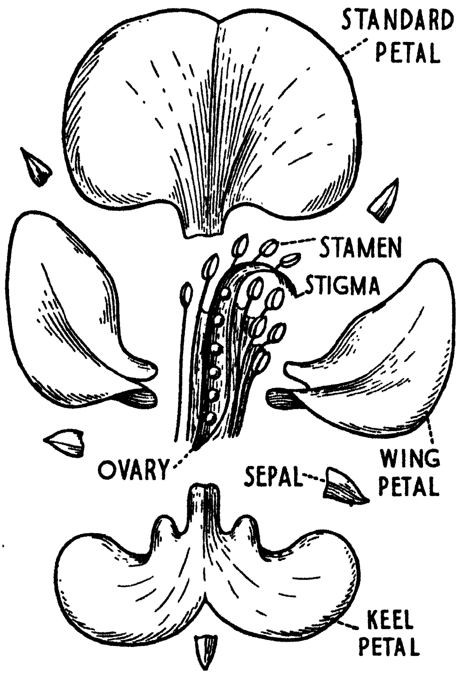


Fig. 347. Parts of the Everlasting Pea Flower.

The flowers of Peas and Beans vary in colour and size, but have similar parts which are very characteristic in form. There are five joined sepals making the calyx. The corolla is composed of five petals which are very characteristic in shape and arrangement (Fig. 347). The posterior one is the largest and most attractive, consequently called the standard. Laterally, there are two so-called wing petals which spread themselves out when the flower is ready for pollination, and have earned for these flowers the term "butterfly flowers." Two other petals are joined in the anterior plane, and because of their shape

and the fact that they contain the androecium and gynaecium are called the keel. The wing and keel petals are hinged together so that when a bee visits this flower they are depressed and release to some extent the stamens and stigma. A heavy insect is needed to do this, for which reason they are also called bee flowers. There are ten stamens inside the keel, which all have their filaments joined to make a sheath round the ovary in Beans. There is only one carpel in the superior position, and this has a row of ovules in the posterior position.

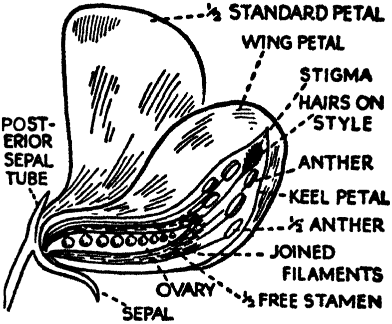


Fig. 348. Sweet Pea. Median half-flower.

This flower can only be cut in half along the median plane, and is therefore said to be **zygomorphic**, which is indicated by the sign ↙. The floral formula is:—

$$\swarrow K\ (5)\ C5\ A\ (5 + 5)\ G\underline{1}.$$

In Peas (Fig. 348) the posterior stamen does not join into the sheath (Fig. 349). The floral formula is therefore:—

$$\swarrow K(5)\ C5\ A\ (5 + 4) + 1\ G\underline{1}.$$

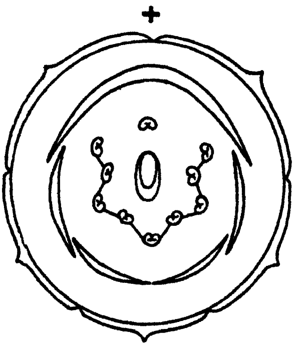


Fig. 349. Sweet Pea. Floral Diagram.

As the stamens and stigma are close together inside the keel, it is possible for Peas and Beans to be self-pollinated. Their only insect visitor is the bee. In Beans there is no

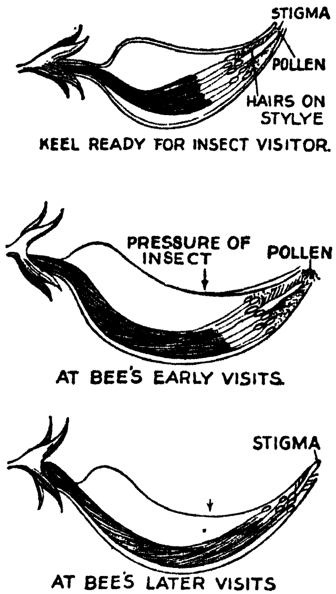


Fig. 350. Pollination of Pea.

nectar, and the bee is the only insect that has any use for the other material the flower has to offer, namely pollen. In Peas, where the posterior stamen is free, nectar occurs at the base of the standard petal, but to reach it, it requires an insect that is heavy enough to weigh down the wings and keel. The keel petals are so firmly joined together that the stamens do not emerge. A little pollen is pushed out of the tip of the keel by hairs on the style at each visit of the insect (Fig. 350). When all the pollen has gone, the stigma emerges from the tip of the keel during the bee's visit in order to receive pollen.

The fruits of Peas and Beans are **legumes,** commonly called pods. Each consists of one superior carpel containing a row of seeds. When quite ripe the fruit becomes dry and dehisces down both sides (Fig. 351).

5. DAISIES

The common Daisy of our meadows and lawns, *Bellis perennis*, has a short, erect, underground stem, by means of which it perennates. It spreads by short branches, called **offsets** (Fig. 352). Each year from this stem, simple leaves are produced very closely together so that they form one

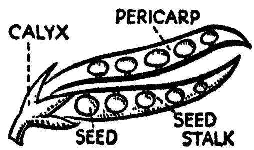


Fig. 351. Pea.
Legume after dehiscence.

circle just above the ground. The radically arranged leaves have no petioles. They are pinnately net veined. In the axils of these leaves stalks arise which terminate in an inflorescence, known as a **capitulum.** This consists of a large number of very small flowers, or florets, the youngest of which is in the centre on a flattened receptacle. This arrangement is derived from a raceme, by telescoping down the main axis and suppressing the small stalks to the florets. The whole group of florets is surrounded by a circle, or involucre, of bracts. If the capitulum be cut in half the form and arrangement of the florets can be seen more easily (Fig. 353).

Fig. 352. Daisy.

There are many well known garden daisies, *e.g.* Michaelmas daisies, which are species of **Aster.** The capitula of these are larger for examination and the florets can be easily removed from the half capitulum. The outer ray florets have an inferior ovary, above which is a narrow corolla tube containing the style, and having a little nectar at the base. When the floret is old enough, the style is terminated by two stigmas (Fig. 354). The flat strap-shaped piece of the corolla has four ridges running down it. These indicate that it is made of five joined petals. Such florets are called ligulate (Lat. *ligula* = a strap) because of the shape

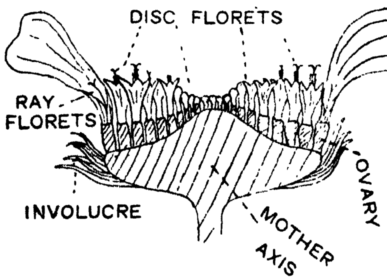


Fig. 353. Daisy.
Vertical section of capitulum.

of their corolla. The bifid stigma indicates two joined carpels, although there is only one ovule in the ovary, attached to the base of it. At the top of the ovary is a circle of very small hairs. These are a modified calyx, known as a pappus. The floral formula for this floret is:—

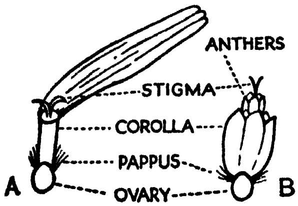


Fig. 354. Michaelmas Daisy. A, Ray floret; B, Disc floret.

$\swarrow$ K pappus C(5) A0 G($\bar{2}$).

The inner disc florets have a small, tubular, epigynous corolla with five little tips showing clearly the five joined petals. These florets have nectar, a similar ovary, style, and stigmas, but in addition, they also have stamens. There are five stamens, which are very small, and joined to one another by their anthers (Fig. 354), thus making a small tube which encloses the style, and, while they are young, the stigmas. The stamens are said to be syngenesious, that is, to have arisen together. The stamens are also epipetalous; very small, slender filaments being fastened to the corolla-tube, so that the stamens alternate with the petals. A pappus calyx is also present. The floral formula for these florets is:—

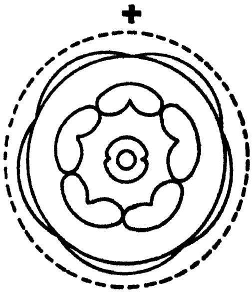


Fig. 355. Daisy. Floral diagram.

$\oplus$ K pappus {C(5) A(5)} G($\bar{2}$),

and the floral diagram is shown in Fig. 355. It should be noticed that these are regular in form, while the ray florets are irregular. The disc florets may be called tubular florets because of the shape of their corollas, and a median vertical section of one is shown in Fig. 356.

When the disc florets first open, the stamens peep out at the top of the corolla tube. A little later a mass of pollen grains may be seen surmounting them (Fig. 357). This pollen was shed by the anthers on their inner side, that is, introrsely, and thus filled up the inside of the very small tube they made. Then the style elongated, and pushed it out. These florets very definitely ripen their stamens before their stigmas, and are therefore protandrous. After a while the tip of the style emerges from the pollen and later it bifurcates into two stigmas. It is the surfaces which were pressed together and hidden that

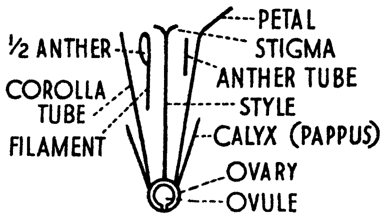


Fig. 356. MICHAELMAS DAISY. Median vertical section of a floret.

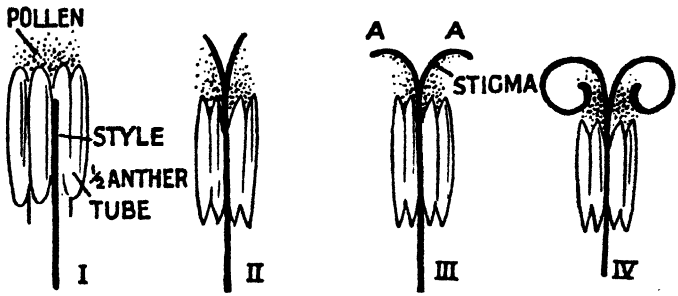


Fig. 357. DAISY.
Stages in pollination. A, Receptive surface of stigma.

need to receive pollen, if seeds are to be formed. Thus there are two very distinct stages in these florets; one which may be called the male stage, when the pollen is ready to be carried away by a visiting insect; and one which may

be called the female, when the stigmas are spread out to receive pollen from the visitor.

There is a third stage to be seen in the oldest florets of a capitulum. Should any floret not be pollinated by a visiting insect, the stigmas elongate and curl round so that their upper surface comes in contact with the style, which collected pollen from the stamens as it grew through the anther tube (Fig. 357). Thus the stigmas receive pollen from their own flower and pollinate themselves. This is known as self-pollination, and ensures pollination occurring, and therefore the development of fruits containing seeds. After pollination, the corollas fade and the ovaries develop into fruits each with one seed inside, so that a capitulum of fruits takes the place of the capitulum of florets. These fruits, which are dry, do not open; they are formed from an inferior ovary of two joined carpels, and are called cypselas.

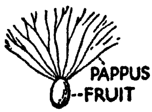


Fig. 358.
MICHAELMAS DAISY FRUIT.

A capitulum affords a wonderful example of co-operation and sharing of the work to be done. It has been noticed that the florets of Daisy have an unusual calyx. Now the normal functions of the calyx are to protect the flower while it is still a bud, and then to support the petals, stamens, and carpels, thus helping to hold the parts firmly together. In the Daisy, however, these functions are performed by the involucre of bracts, not for one floret at a time, but for the whole head which may comprise a hundred or more individuals.

Moreover, the florets of this capitulum are pollinated by insects, but the work of attraction is done entirely by the ray florets for the whole head. The disc florets produce all the pollen needed to pollinate themselves, and also the ray florets, where the stamens have been sacrificed so that the petals might grow larger.

Further, the style helps the stamens to put their pollen in a suitable place for dispersal. Each floret makes only one

seed, but it is almost certain to make that one, which will receive all the nourishment, and therefore stand a better chance of being a good seed than if there were many.

The calyx has no real function in the flower, but after pollination it grows and makes a mass of fluffy hairs at the top of the fruit (Fig. 358). This enables the fruits containing the seeds to be blown away easily by the wind. This calyx development is called a pappus.

6. SUNFLOWER (*Helianthus*)

Sunflower is a familiar garden plant which has a capitulum of yellow florets very closely resembling that of the Daisy. It is much larger and the corollas are all yellow. There is no pappus for the dispersal of the fruits by the wind. By the time the seeds are fully developed and the fruits ripe, the capitulum will have bent over so that as the wind sways it to and fro the fruits will be swung out, the outer ones first, and last of all those in the centre.

These one-seeded fruits of the annual species are commonly sold by corn chandlers and seed merchants as seeds, and parrots are very fond of them. In their treatment of them the parrots clearly demonstrate that they are fruits, because they crack the case into the two carpels into which it readily splits, and eject them from their beaks usually one at a time. This being done, the parrot now enjoys the seed.

The fruit wall, or pericarp, varies in colour a good deal, but is usually striped and quite firm and brittle. Inside the pericarp the embryo is enclosed in a thin delicate testa. The embryo consists of two rather oily cotyledons and a very small plumule and radicle.

This plant has tall, aerial stems, bearing simple leaves with pinnate net veins. The perennial species have in the soil a long, thin, horizontal underground stem, rhizome (see p. 324), with rather swollen ends bearing the buds from which the aerial shoots develop (Fig. 359). The

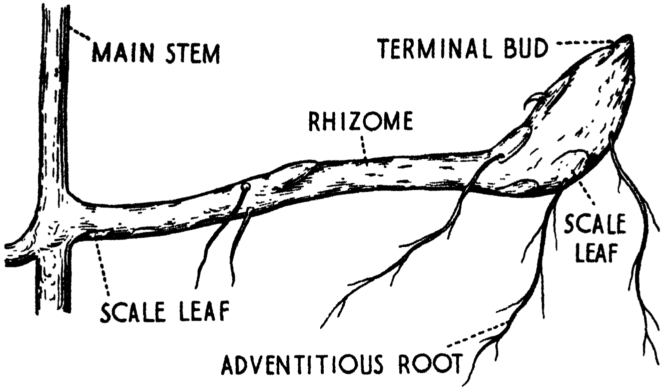


Fig. 359. SUNFLOWER RHIZOME.

rhizome contains reserve food and is a perennating organ. Similar rhizomes will be found in many familiar garden plants. The Jerusalem Artichoke resembles a giant Sunflower in many ways, but has a number of thin underground stems with their ends very much swollen (Fig. 360). These are the edible Artichokes. They are called **tubers**, and bear scale leaves, in the axils of which buds arise for the new growth of next season. The well-known Potato is also a tuber, similarly produced; the "eyes" are the buds protected by the scale leaves.

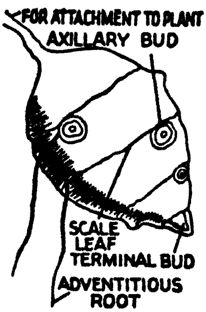


Fig. 360. JERUSALEM ARTICHOKE. Stem tuber.

7. STEM STRUCTURE

The aerial stems of herbaceous plants grow rather quickly and only last one year, so that there is very little secondary growth. Very often special strengthening tissue is produced, usually in the cortex, sometimes associated with the vascular bundles.

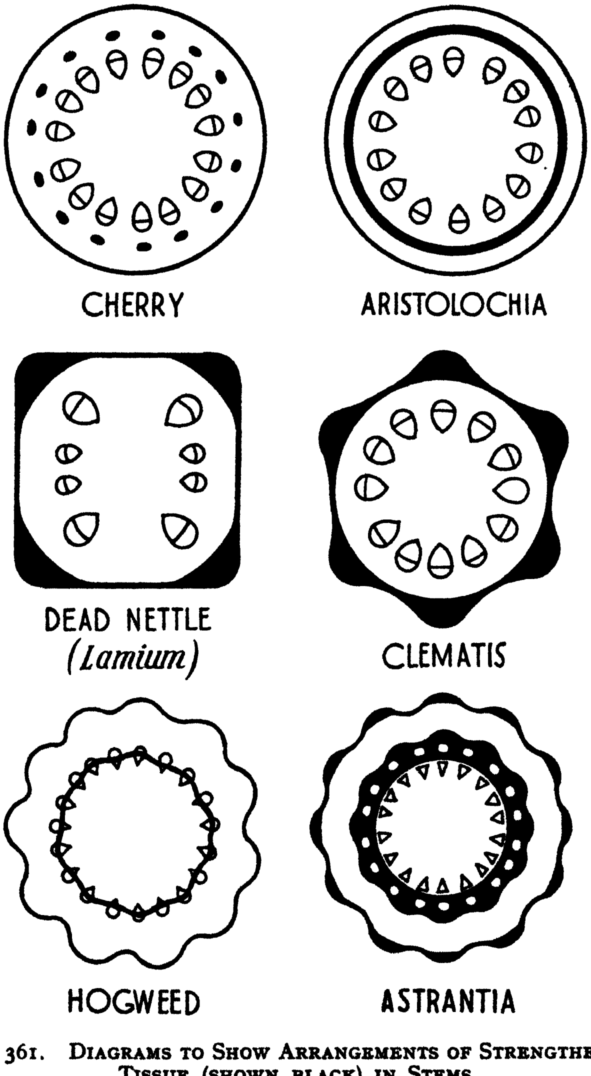


Fig. 361. Diagrams to Show Arrangements of Strengthening Tissue (shown black) in Stems.

Collenchyma, when present, usually occurs immediately beneath the epidermis, and often in parts that are green. Sclerenchyma may be arranged in a variety of ways (Fig. 361) to give stability and flexibility according to the size of the plant, type of foliage and flowers, and the characteristic environment in which the plant grows.

Many herbaceous dicotyledons are **perennials**, but some only live through one winter and are therefore **biennials**; while others have to be grown from seed each season, and are termed **annuals**. Amongst the biennials are some common plants used for food, *e.g.* Carrot, Turnip, Parsnip (Fig. 362). These plants in their first year of development from a seed produce an underground vegetative organ, *e.g.* the main root, containing as much food as possible. No flowers are produced in the first year. In the second spring, if allowed to, these underground parts develop foliage quite quickly and have enough stored food to produce flowers, which, if pollinated and the ovules fertilised, will form fruits containing seeds. At the end of the season there is no underground food store, and the original plant dies, but seeds have been formed to produce new plants.

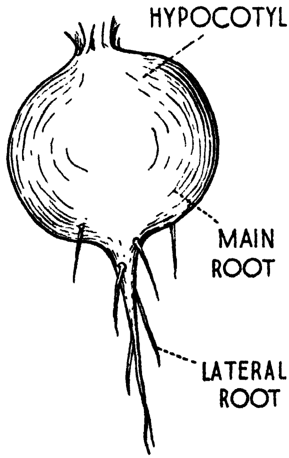


Fig. 362.
Turnip Root.

8. SEEDS AND SEEDLINGS

The seeds of herbaceous dicotyledons may resemble the Pea seed [described in Chapter XVIII.] with regard to structure, or may contain endosperm.

Let us consider the seed of **Castor Oil** (*Ricinus*). This varies in size a good deal, from about a quarter of an inch in length to rather more than a half. It also varies in colour from light brown, speckled with fawn, to a very dark brownish-black. The testa is hard and shiny. The appearance is such that birds often mistake castor-oil seeds for beetles, pick them up, and fly off with them, thinking them to be prey. When they later find out their mistake they throw the seed away. This, however, plays a useful part in getting the seed carried to an entirely new home.

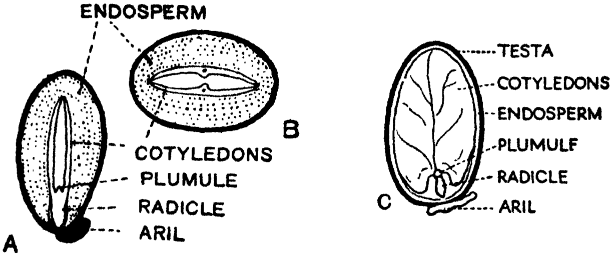


Fig. 363. Seed of Castor Oil.
A and C, Longitudinal sections; B, Transverse section. The dark outline is the testa.

At the narrow end of the seed is a cream, very much wrinkled body, which swells considerably when the seed is soaked (Fig. 363). This is called an **aril**, or it may be called an **oil-body**, because it contains oil for which ants collect these seeds. The ants only want the aril, so very often when they have struggled a good way with this very heavy load, they bite off the aril and leave the seed behind. This again disperses the seed, because it still has the power of germination.

If the testa be removed from a soaked seed, a solid oily mass will be found within. This is endosperm, and it must be cut lengthwise in three directions to discover the embryo (Fig. 363, A, B, C). In the centre of the endosperm are two

flat, thin, transparent cotyledons, which lie across the broad way of the seed. Between them, at the aril end, there is an exceedingly small plumule and a very minute radicle which protrudes from them into the endosperm. This seed is therefore a dicotyledon with endosperm.

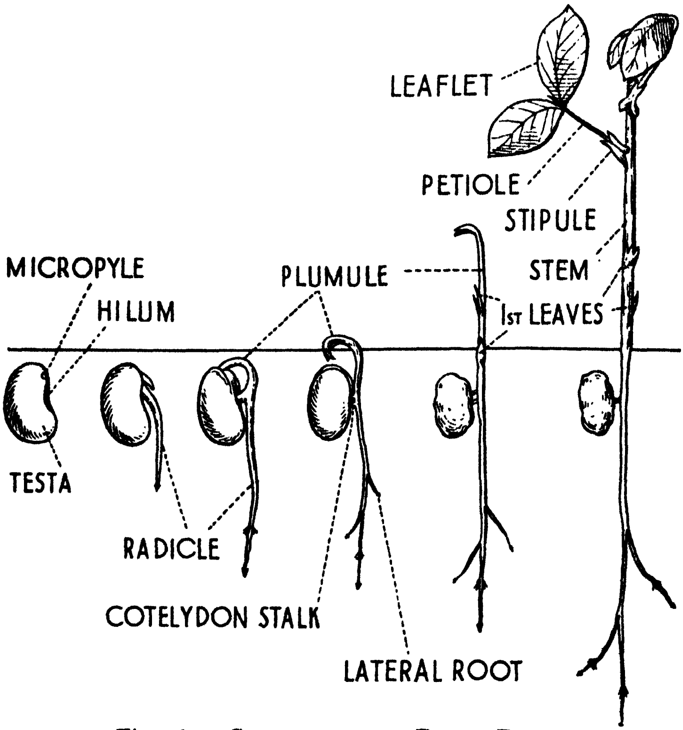


Fig. 364. Germination of Broad Bean.

On germination the cotyledons of seeds may or may not be brought above the ground, and when endosperm is present they will digest it. **Pea** is a hypogeal seedling without endosperm. **Broad Bean** and **Runner Bean** are also of this type, and like Pea show some preliminary stages in the

development of the foliage leaves (Fig. 364). **French Bean** and **Sunflower** have a seed without endosperm, and the cotyledons are epigeal, that is, they come above the ground. In this type of germination, the hypocotyl elongates considerably, and in an arched form pushes its way through the soil. It brings with it the cotyledons,

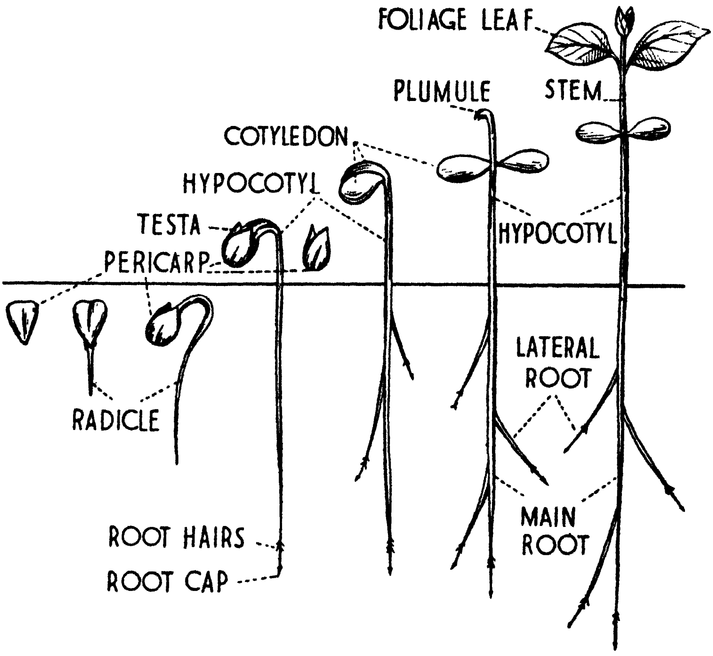


Fig. 365. GERMINATION OF SUNFLOWER.

with the plumule between them, partially covered by the testa (Fig. 365). Later the testa drops off, and the cotyledons separate. After a time the plumule develops, forming the stem bearing foliage leaves (Fig. 365). It will be noticed that the cotyledons became green and performed the work of normal green leaves, helping to manufacture

food for the young plant. They have their own particular form, which is not the same as that of the foliage leaves.

Mustard and **Cress** are familiar examples of epigeal seedlings, which are grown for sale just at the stage when the cotyledons have expanded and become green. They are interesting to grow further on to obtain the stem and foliage leaves.

In **Castor Oil**, a dicotyledon seed with endosperm (Fig. 363), the cotyledons digest the endosperm; in this case a main root develops, and the hypocotyl grows out in a hooked form (Fig. 366), pushing through the soil and

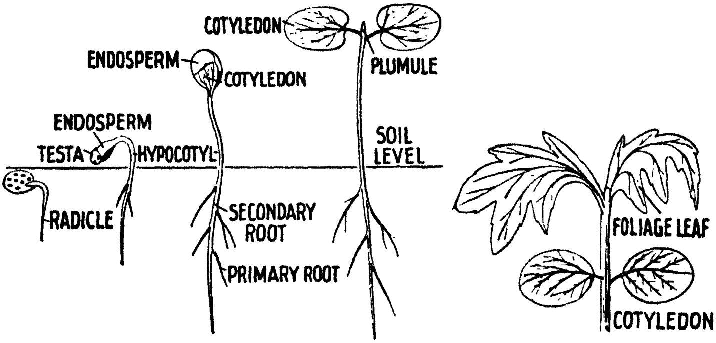


Fig. 366. Germination of Castor-Oil Seed.

bringing the cotyledons, endosperm, and testa with it. The hypocotyl grows up, straightens, and the cotyledons become green, remaining for some time with their tip buried in the endosperm, so that it may all be digested and none of the food-store wasted. Later the epigeal cotyledons become quite free and expand as flat green leaves; then the plumule develops, and bears its characteristic foliage (Fig. 366).

The seedlings chosen show the three different functions cotyledons perform:—(1) the storage of food, (2) the manufacture of food, (3) the digestion of stored food.

9. INFLORESCENCES

When many flowers are placed sufficiently close together to make one group, they assist one another considerably from the point of view of attractive power. It is the many flowers on one main stalk in Larkspur, Lupin, Laburnum, which make them so beautiful and attractive. The numerous small flowers making a flat group in Elder, or a capitulum in Sunflower (Fig. 353), render them sufficiently conspicuous and attractive to be noticed; if they occurred singly it is improbable that insects would ever find them. The grouping of flowers is therefore a great economy scheme, each individual flower spending very much less on attractive material, such as large petals, than it would have to do if it stood alone. In addition to this each individual flower spends less on nectar to reward the insect for its work, than would be necessary to make it acceptable if there were not a second sip close at hand.

The grouping of the flowers also results in economy of labour on the part of the insect, because many flowers in the same inflorescence will be pollinated by what may be regarded as one visit, because there is no intervening journey worth mentioning.

When flowers are produced in clusters on one main axis, the length of period when pollination may be effected for the group is increased. The flowering period of the main stem is increased, so that although the individual flowers last no longer, there is less material wasted should the weather, or any other circumstance, not prove favourable immediately for pollination. The increased life of the groups may make it possible for the unfavourable condition to pass, and some fruit and seed be successfully produced and dispersed, so that the entire effort and material are not wasted, as in the case of solitary flowers which meet with temporary hardships.

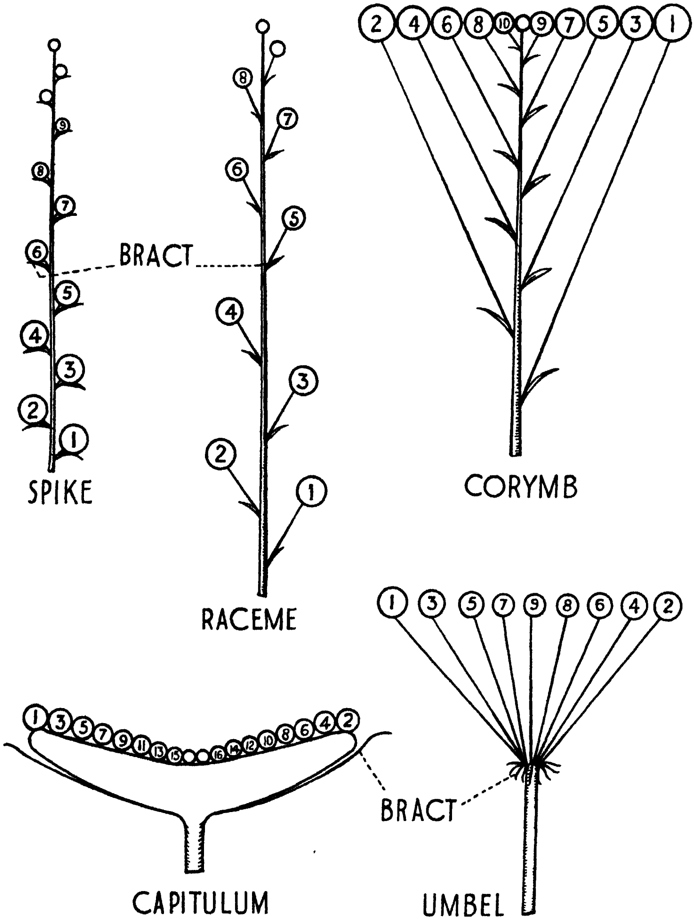


Fig. 367. PLANS OF RACEMOSE INFLORESCENCES.

There are two main types of inflorescence. Those in which the main axis continues for some time to grow indefinitely are called **racemose.** The primary arrangement of this type, called a **raceme,** has already been noticed in *Lilium.* The flowers are stalked, spirally arranged with the youngest at the top, and may or may not occur in the axils of bracts (Fig. 367). Some inflorescences exactly resemble a raceme except that the flowers have no stalks, *e.g.* Plantain (*Plantago*). This is called a **spike.** Another modification of a raceme has the flower stalks unequal in length, so that all the flowers form a flat head, called a **corymb.** Candytuft has a corymb, and in some cases, *e.g.* Wallflower, the youngest flowers at the top of a raceme form a corymb while the inflorescence is young. The **capitulum,** already described in this chapter, is a racemose inflorescence. *Polyanthus* furnishes an example of an **umbel.** In this the flowers form a flat head, being arranged in a spiral around the growing point, the youngest being in the centre.

Inflorescences in which the growth of the main axis is soon ended by a flower arising at the tip are called definite or **cymose.** They branch, and the branches also end in a flower. When only one branch is produced at a node, *e.g.* Buttercup, it is called a **one-sided cyme,** or **monochasium.**

Sometimes all the branches of a one-sided cyme are produced on the same side; this necessitates a certain amount of coiling, and gives a very characteristic appearance (Fig. 368). This occurs in Forget-me-not.

In Campion and Chickweed the main axis ends in a flower, and then a pair of branches from one node produce two flowers of equal age. This is a **two-sided cyme,** or **Dichasium.** The growth is continued by each branch producing another pair of flowers, so that there are four of equal age, and each of these may produce two more, and so on. It is quite common to find that, after several branches have been produced, there are so many flowers of the same

age, that, owing to limited space, light, and food supply, one is suppressed, so that the inflorescence becomes monochasial. There are many cases where the lateral branch, instead of ending in a flower, produces another inflorescence either of the same or of a different kind.

Compound umbels are much more common than simple umbels. They occur in all the Parsleys. The main axis produces an umbel, and the lateral axes form umbels, so that it becomes an umbel of umbels.

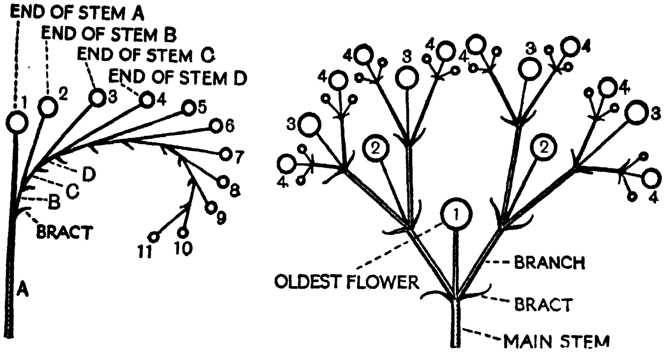


Fig. 368. Diagram of Monochasium and Dichasium.

When the lateral growth is not a repetition of the main growth it is said to be mixed. Thus a corymb of capitula occurs in ragwort, a dichasium of capitula in chrysanthemum.

10. POLLINATION

Whilst examining flowers and their parts we have noticed that considerable trouble is taken to give opportunity for pollen to be brought from another flower, and self-pollination is more a last resource than a thing to be desired. Experiment and observation have shown that cross-pollination leads more often than self-pollination to the production of stronger, healthier offspring.

A wind-pollinated, or **anemophilous,** flower has already been mentioned in Chapter XIX., where its characters were noted. Many flowers are specially adapted for insect pollination, and are called **entomophilous.** They are coloured, and therefore easily noticed, may possess nectar, and sometimes have scent. These flowers provide a platform for the insect, and the anthers and stigmas are so placed that the insect will touch them while securing nectar. The pollen grains are somewhat sticky, because they possess irregular surfaces, and they therefore readily adhere to the insect's body.

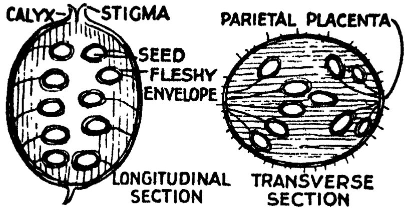


Fig. 369. Gooseberry Fruit.

Different flowers are adapted to different insects with regard to accessibility of the nectar. In Cherry, Buttercup, and Daisy any insect can find, and reach the nectar, even small flies, although they have no long mouth parts. Often the nectar is too deep within the flower to be reached by an insect with mouth parts shorter than those of a bee, *e.g.* Bluebell; and occasionally it is accessible only to butterflies and moths, *e.g.* long-spurred varieties of Columbine (*Aquilegia*). Bees are known to have a preference for blue and violet, while

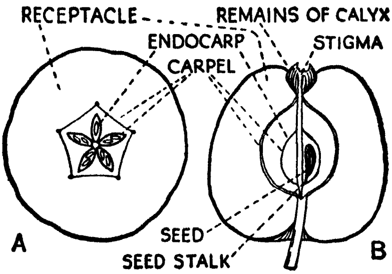


Fig. 370. Fruit of Apple.
A, Transverse section; B, Longitudinal section.

moths visit white and pale yellow flowers more particularly, because these are easily seen in the twilight, which is the time moths choose to fly abroad.

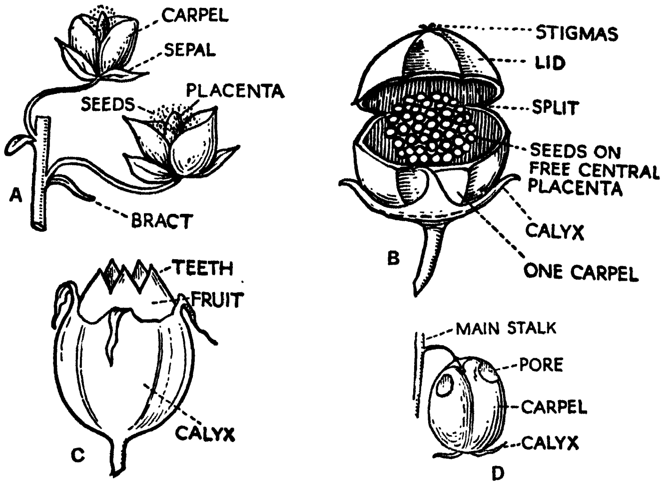


Fig. 371. Dehiscent Fruits.
A, Foxglove (slightly reduced); B, Scarlet Pimpernel; C, Corncockle; D, Campanula.

11. FRUITS

There are two main classes of fruit, namely succulent and dry. Cherry fruit, already described, is a **succulent fruit**, characterised by the possession of a stone and one

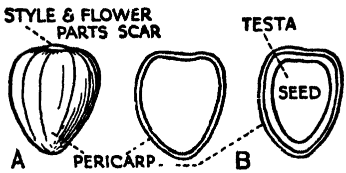


Fig. 372. Fruit of Sunflower.
A, Whole; B, Opened.

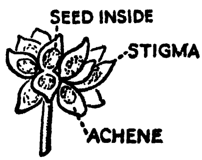


Fig. 373. Fruit of Buttercup.

seed. It is called a **drupe.** Many fruits have both the mesocarp and endocarp succulent. Most of these possess more than one seed and are **berries,** *e.g.* Gooseberry (Fig. 369). Essentially a fruit is a ripened ovary, but

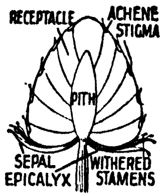


Fig. 374. HALF-STRAWBERRY FRUIT.

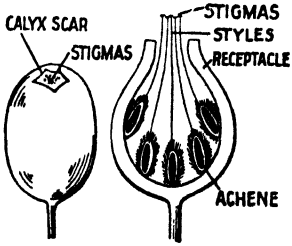


Fig. 375. ROSE HIP.

sometimes other parts of the flower take place in its formation. Thus a fruit may best be defined as those parts of a flower which persist and develop after fertilisation. Sometimes the receptacle persists and becomes swollen and succulent, forming a succulent, **false** fruit, *e.g.* apple (Fig. 370).

Dry fruits containing many seeds usually split in order to release them. They are said to be **dehiscent.** Pea fruit, a dry dehiscent fruit with only one carpel, is a **legume.**

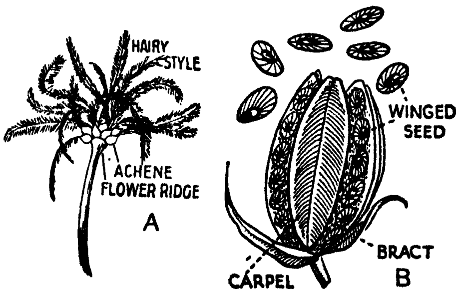


Fig. 376. A, FRUIT OF CLEMATIS; B, FRUIT OF GLADIOLUS. After Dehiscence (slightly reduced).

The majority of dry dehiscent fruits with several carpels are **capsules.** They dehisce by splitting or by pores (Fig. 371).

If a dry fruit contains only one seed, it does not split, and is said to be **indehiscent.** Cereals, *e.g.* Maize, have dry, indehiscent fruits in which the pericarp and testa are firmly united. This kind of fruit is a **caryopsis.** In a Maize grain a small scar, left by the stigma, just above the white embryo denotes that it is a fruit and not a seed. **Nuts** are dry, indehiscent fruits of more than one carpel, but sometimes a fruit that we call a nut is the centre part of a drupe, *e.g.* Almond, Walnut. The " compound " flowers, that is, those which form capitula like Daisy, have dry, indehiscent fruits, which are inferior and consist of two carpels, and are called **cypselas** (Fig. 372).

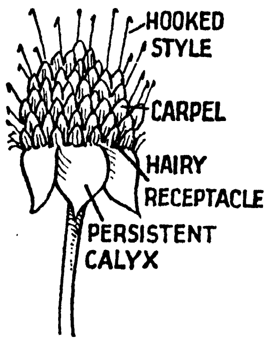


Fig. 377. Geum Fruit.

When the carpels of a flower remain free they form a **compound** fruit, *e.g.* Buttercup (Fig. 373). Some compound fruits are false, as they have a succulent receptacle, *e.g.* Strawberry and Rose hip (Figs. 374 and 375).

Fruits and seeds are often adapted for **dispersal** by some definite agent. Those scattered by wind have either wings or hairs (Fig. 376). Seeds of succulent fruits are scattered by birds; and some fruits have hooks which cling to the fur of animals, and are thus carried by them (Fig. 377). A few seeds, *e.g.* Water-lily, are light and watertight, and therefore dispersed by water.

CHAPTER XXI

THE MAIN DIVISIONS OF THE PLANT AND ANIMAL KINGDOMS

1. INTRODUCTORY

The members of a group of plants or of a group of animals may be so similar that they are all placed in the same genus, in which case they are all given the same first name and distinguished from one another by the second or specific name. When genera are compared it is found possible to group them into orders. The orders fall into classes, the classes into phyla, and the phyla into sub-kingdoms of the two great kingdoms, plant and animal.

The **plant kingdom** has two great divisions, Cryptogamia, consisting of the simpler plants, and Spermatophyta.

2. CRYPTOGAMIA

This name means " hidden marriage," and was given because the sexual union was obscure until methods of magnification improved. They multiply mainly by means of spores.

THALLOPHYTA.—The vegetative part of these plants is simple in form, and consists of a thallus. They usually show no alternation of generations. The following groups can be distinguished:—

(1) **Bacteria.** These microscopic organisms have no highly organised nucleus and no chlorophyll. Most of them are either parasites or saprophytes (see p. 578), and a distinctive feature is their reproduction by simple fission.

(2) **Algae.** Algae occur in both marine and fresh water. They possess chlorophyll. Some are unicellular, e.g. *Chlamydomonas*; some multicellular filaments, e.g. *Spirogyra*, and other multicellular forms have a quite complex external appearance, e.g. *Fucus*.

(3) **Fungi.** These vary in form like the Algae, but have no chlorophyll. Those that we have studied belong to three groups, namely Phycomycetes, or algal fungi; Ascomycetes, which have ascospores; and Basidiomycetes, which have basidiospores.

BRYOPHYTA.—These have characteristic sexual organs, namely antheridia and archegonia. They also have asexual spores. The sexual organs occur on one generation, and the asexual spores on another; and these two alternate regularly.

(1) **Hepaticae** (Liverworts). The sexual generation is a thallus, usually dorsiventral, and either dichotomously divided or sometimes leafy.

(2) **Musci** (Mosses). The sexual generation is divided into stem and leaves.

PTERIDOPHYTA, e.g. *Pteris Aquilina*.—In these the asexual generation has become the evident plant, having stem, root, and leaves, and internally a complicated vascular tissue. The sexual generation is small, being called either the prothallus, or the gametophyte, and bearing antheridia and archegonia.

3. SPERMATOPHYTA

These are seed-bearing plants: they retain the asexual generation as the large, complex plant, and they are heterosporous, having one kind of spore which gives rise to a prothallus bearing male sexual organs, and another kind producing a prothallus with female sexual organs.

The vegetative parts of the prothalli are very greatly reduced. They reproduce by means of seeds.

GYMNOSPERMS.—Gymnosperms means naked seeds; these plants have their seeds in cones, but not enclosed inside carpels, e.g. *Pinus*.

ANGIOSPERMS.—Angiosperms have their seeds enclosed in carpels, which later form fruits. The stamens containing pollen and the carpels are usually surrounded by sterile leaves, the whole making a flower, which is often attractive for insect pollination. The group is divided into **Monocotyledons,** e.g. *Lilium*, and **Dicotyledons,** e.g. *Prunus*. The dicotyledons further show three main divisions: (1) Apetalae, being plants in which the flowers have no petals, as in catkins; (2) Polypetalae, in which the petals are free; (3) Sympetalae, in which the petals are joined.

The following pages give an outline of some of the groups and divisions in the **animal kingdom.** They may be divided into two sub-kingdoms, viz. (1) Sub-Kingdom Protozoa, and (2) Sub-Kingdom Metazoa.

4. SUB-KINGDOM PROTOZOA

The members of this are unicellular or colonial. The latter are composed of several cells all holding together and all alike in structure and function.

PHYLUM: PROTOZOA. *Class*: **Rhizopoda.** Animals move by means of pseudopodia, e.g. *Amoeba, Plasmodium*.

Class: **Flagellata.** Animals move by means of flagella, e.g. *Euglena*.

Class: **Ciliata.** Animals move by means of cilia, e.g. *Paramecium*.

Class: **Sporozoa.** Animals are internal parasites, e.g. *Monocystis*.

5. SUB-KINGDOM METAZOA

This includes all the remaining phyla, since all other animals have many cells, the cells not being all alike in structure or function.

A. PHYLUM: COELENTERATA. Body has only two layers of cells, namely ectoderm and endoderm, and only one cavity with one main opening to it. The body is radially symmetrical, e.g. *Hydra, Obelia.*

B. PHYLUM: PLATYHELMINTHES. These are flat, bilaterally symmetrical animals, having only one opening to the alimentary canal.

Class: **Turbellaria.** Free-living, ciliated flat-worms, e.g. *Planaria.*

Class: **Trematoda.** Parasitic forms, e.g. *Distomum* (*Fasciola*), Liver Fluke.

Class: **Cestoda.** Parasitic forms, e.g. *Taenia.*

C. PHYLUM: ANNELIDA. Bilaterally symmetrical, segmented bodies with a coelom, closed blood-vascular system, and a double ventral nerve cord. Covered with thin cuticle.

Class: **Polychaeta,** e.g. *Nereis.*

Class: **Oligochaeta,** e.g. *Lumbricus.*

D. PHYLUM: ARTHROPODA (Gk. *arthron* = joint: *pous* = foot). These animals have segmented bodies, but they have paired, jointed appendages, some for locomotion, and usually one or more pair for use as jaws. The coelom is very reduced, and the blood-vascular system open. They have a thick cuticle.

Class: **Crustacea.** Most of the members of this class are aquatic, and therefore usually have gills. The body is divided into two parts, and there are two pairs of antennae. The crayfish and the crab illustrate the features of members of the Crustacea.

A fairly common member is the **Crayfish.** *Astacus torrentium* occurs somewhat rarely in English rivers, especially in those flowing over chalk or limestone. They are only about three inches long, and those seen for sale are a larger species, *A. fluviatilis*, which have been imported from the Continent. When alive the crayfish is dull green, but the Continental species has red colour on the pincers and legs. Those in the shops have been boiled, and become red in the process.

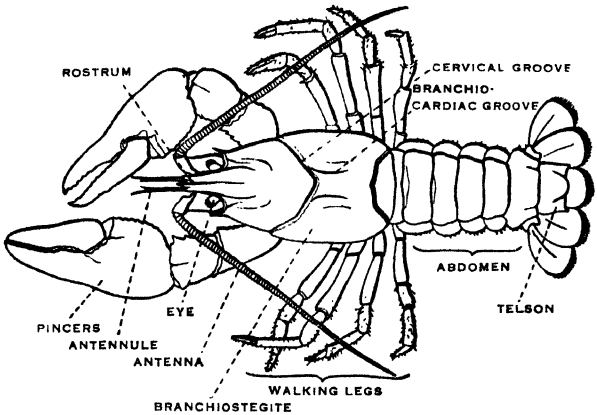


Fig. 378. THE CRAYFISH.
Dorsal view. (After Huxley.)

They make holes in the river banks and remain in these during the daytime. At night they crawl about in search of food—both animal and vegetable food, either living or dead. They seize their food and hold it with their pincers.

The crayfish cannot swim like a fish, because its whole body is covered with a thick shell strengthened by calcium salts, so that it is like a knight encased in armour. The body is segmented as in the cockroach, and between the segments there is only a thin skin, so that some movement is possible dorso-ventrally; but none from side to side. The front half

of this body, the cephalothorax, is enclosed in a single unsegmented piece of armour, the carapace, in which a groove—the cervical groove—just shows the division between the head and thorax. The armour behind this groove is extended on each side of the body as a gill cover, or branchio-stegite. The branchio-cardiac grooves mark the edges of the gill covers.

The abdomen consists of six segments and an unseg-

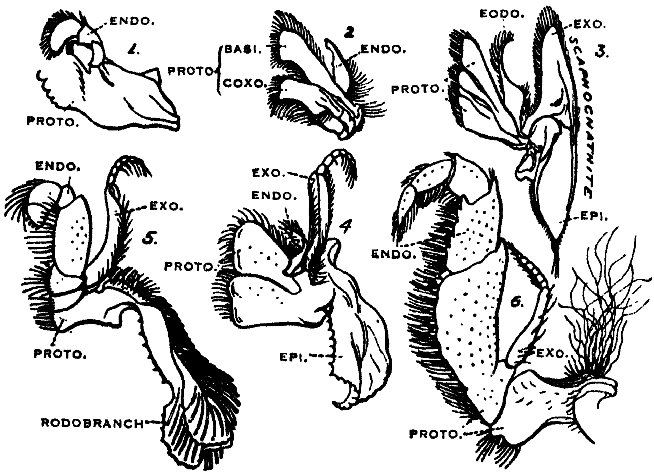


Fig. 379. Appendages of Astacus.

1, Mandible; 2, First maxilla; 3, Second maxilla; 4, 5, and 6, First, second, and third maxillipedes. All are drawn in the inverted position (dorsal part downwards). (After Huxley.)

mented last piece called the telson. The armour of each abdominal segment consists of a dorsal piece—the tergum, and a ventral piece—the sternum. These are joined by side pieces called the pleura. The terga overlap one another from before backwards, and slide over one another as the abdomen is bent and straightened.

The crayfish has nineteen pairs of limbs or **appendages.** Each pair of appendages arises from a different body

segment. There are six pairs on the abdomen, and the remaining thirteen on the segments of the head and thorax, six of which form the head, and eight the thorax.

The appendages are attached to the sternum and covered by jointed armour, continuous with that of the body. The appendages vary a great deal in appearance because they have different uses, but all really possess the same parts, namely a two-jointed basal part—the protopodite—which bears two branches (Fig. 379, 6). The joint of the protodite nearest the body is known as the coxopodite, and the next as the basipodite. The branch nearest the centre of the body is the endopodite, and the outer one the exopodite.

The parts are best seen in the pair of third maxillipedes, which are immediately in front of the pair of great pincers, and occur on the ninth segment: they are used for pushing food into the mouth. The different appendages have different functions, and their appearance varies accordingly. Fig. 379 shows the mouth appendages. The posterior two pairs, the second and third maxillipedes, each bear a gill.

The following is a list of the body segments with their appendages:—

Head	1. No appendages.	
	2. Antennules.	Sensory limbs.
	3. Antennae.	
	4. Mandibles.	Jaws.
	5. 1st Maxillae.	
	6. 2nd Maxillae.	
Thorax	7. First Maxillipedes.	
	8. Second ,,	
	9. Third ,,	
	10. Chelipeds with great pincers.	Legs.
	11-14. Walking-legs.	
Abdomen	15. One branched limb (no exopodite).	
	16-19. Swimmerets.	
	20. Telson. Tail fin.	

The antennules (Fig. 380) have three joints to the protopodite. The basal joint of each has in it a cavity, called a statocyst, lined with hairs, which communicates with the nerve fibres. In the cavity are grains of sand. If the statocysts are removed the crayfish loses its sense of balance. If the sand grains are replaced by iron filings a magnet can be used to make the animal alter its position. The two many-jointed lashes may be compared with the endopite and exopodite of other appendages. The outer one bears bristles which give the sense of smell. The kidneys, or green glands, of the crayfish, open in the basal joint of the antennae, which bear bristles, giving the sense of touch.

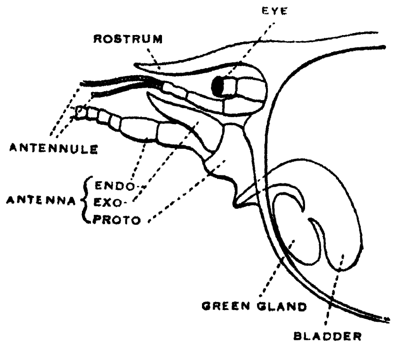


Fig. 380. ASTACUS.
Green Gland and neighbouring parts.

The great pincers or chelae are for defence. The limbs bearing these pincers together with the walking legs and swimmerets are shown in Fig. 381. In the walking legs there is no exopodite, but the endopodite has five joints. The chelae are formed by a projection from the last joint but one, against which the last joint bites. There is a similar, but small pincer, on the next pair of walking legs. The swimmerets have both exopodite and endopodite. They are imperfectly jointed and surrounded by bristles.

In the female the second pair of walking legs—those on the twelfth segment—are pierced by a hole through which the eggs are laid. In the male a similar opening for the escape of the sperms is found on the fourth pair of walking legs. In the female the appendages of the first abdominal

segment are very small and in the male they are tube-like. The telson and the last pair of appendages, which have very broad endopodite and exopodite, form the tail-fin.

The crayfish breathes by means of gills. These occur attached in three places, namely to the limbs, to the membranes joining the limbs to the body, and to the inner wall of the gill chamber. The thin-walled, much branched gills extract oxygen from the water flowing beneath the gill cover and replace it by carbon dioxide. This water is bailed out of the gill covers by the exopodites

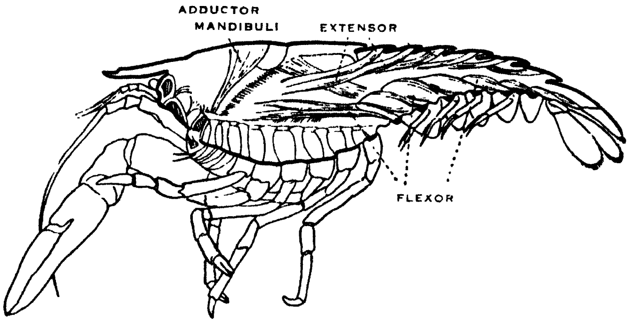


Fig. 381. CRAYFISH.
Median section with abdomen extended to show flexor and extensor muscles.

and epipodites jointly forming the scaphogmathite of the second maxillae, which flaps sixty times per minute. The water sweeps away the excreta, issuing in front of the mouth from the antennae.

The eggs are laid in November, and do not hatch until the beginning of the following summer, but during that time they remain attached to bristles on the abdominal limbs of the mother. When the young are first hatched their pincers are hooked; and they continue to cling for a time to the mother's limbs, so that they are protected from enemies and prevented from being swept away by currents to the sea.

Since the armour, or exoskeleton, is rigid, it cannot grow and thus keep pace with the growth of the body within it; hence the crayfish must moult. The old shell splits down the back and the animal drags itself out. As well as the shell, the lining of part of the alimentary canal is shed, because, as in the cockroach, the front and hind parts of it are merely ingrowths of the ectoderm, and therefore lined by skin, or cuticle, which is a continuation of the external covering.

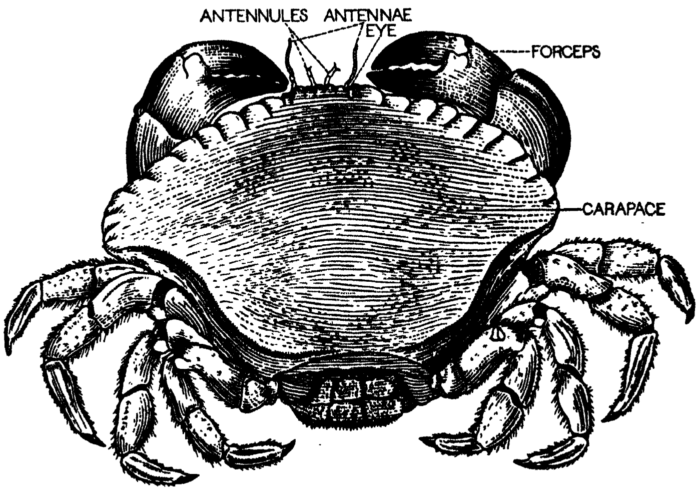


Fig. 382. Dorsal View of Crab.

One of the wonders of the crayfish's moult is how it manages to drag the large fleshy parts of its limbs through the narrow joints in the shell. It is probable that the cells composing them lose a large quantity of water and therefore shrink. Immediately after this process the crayfish is very flabby. It hides under a stone for a few days until the new armour has hardened. An adult moults about once a year, but a young crayfish more often. If a crayfish loses a limb it is capable of growing a new one.

The **crab** (Figs. 382 and 383) is an example of a member of the Crustacea differing somewhat in appearance from the crayfish. The cephalothorax is very large, and the abdomen hidden from sight because it is bent forwards and lies in a groove in the sterna of the thorax. There are sockets in the carapace into which fit the eye-stalks and

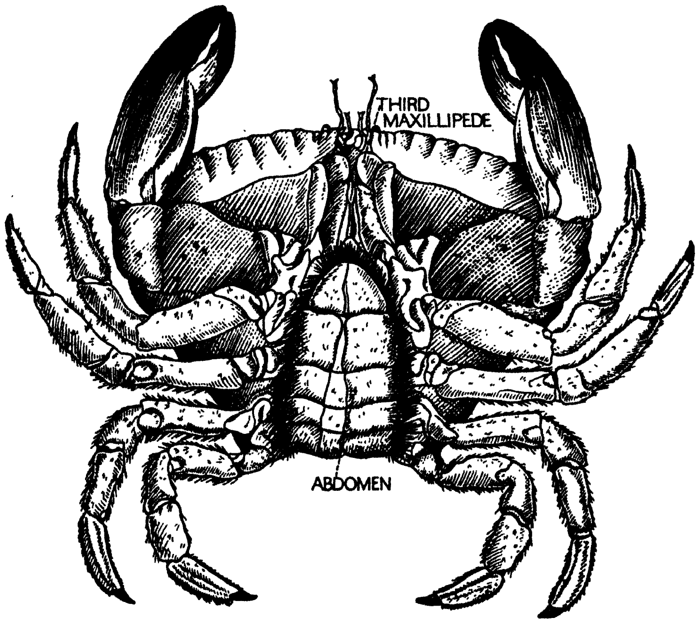


Fig. 383. Ventral View of Crab.

bases of the antennules. Appendages are found on head and thorax as in crayfish, but the third maxillipedes are broad and flat and cover over the maxillae and the other maxillipedes. In the male there are two pairs of abdominal appendages, and in the female four pairs, which carry the eggs. Most crabs are marine, including the common shore crab (*Carcinus*), which may be seen walking in its peculiar

sideways fashion on the beach. In the swimming crabs (*Portunus*) the legs on the last thoracic segment, that is the back pair of walking legs, possess a paddle-like joint. Crabs act as scavengers, devouring dead and decaying matter. If the large tergum of the thorax is removed the gills are seen and it is easier to make out the parts of the maxillipedes.

Several forms of crabs exhibit **commensalism**, that is, they live as messmates with another animal. The tiny pea-crab lives inside the mantle cavity of the mussel and the oyster. In this way it is protected, and in return it destroys organisms that might injure its partner. The hermit crab, which has a soft and twisted abdomen, seeks an empty gastropod shell in which to live. The limbs of the sixth abdominal segment fasten them into the shell, and when they are attacked, contraction of an abdomen muscle enables them to withdraw into it, but they are nevertheless liable to be eaten by fishes. Having found a house, some species allow a sea anemone to live on it. The crab moves actively about with only eyes and claws protruding from the shell, and the sea-anemone benefits by its activity because it itself is more or less stationary, like *Hydra*, and the crab carries it to fresh feeding grounds. It resembles *Hydra* also in possessing nematocysts, and these protect it, and consequently the crab, from fishes.

Class: **Hexapoda,** or **Insects,** have the body divided into three regions, one pair of antennae, three pairs of legs, and usually wings.

Class: **Myriapoda,** having one pair of antennae, numerous pairs of legs, and no wings, are represented by centipedes and millipedes.

Class: **Arachnida** have two regions to the body, no antennae, no wings, and four pairs of legs. The most well-known members of this class are spiders.

E. PHYLUM: MOLLUSCA.—In place of a cuticle these creatures are characterised by the possession of a shell.

The bodies are unsegmented, and the blood-vascular system is open. They have a muscular, ventral organ of locomotion called the foot.

Class: **Lamellibranchiata.** These have a bivalve shell, plate-like gills, and no head, e.g. *Anodonta.*

Class: **Gastropoda.** The shell is in one piece, and the gills are feather- or comb-like or absent (*e.g.* Helix). They have a head and a tongue-like organ, called a radula, on which are rows of teeth, with which snails tear pieces from vegetable matter.

F. PHYLUM CHORDATA.—Segmented bodies with closed blood-vascular system, a large coelom, a hollow, dorsal nervous system, a notochord, and gill slits. The two last are not always present throughout life.

SUB-PHYLUM CEPHALOCHORDA.—Here the notochord runs from end to end of the body and is present throughout life. There is no definite brain, heart, limbs, or skeleton, *e.g.* Lancelet (*Amphioxus*).

SUB-PHYLUM VERTEBRATA.—These animals have an internal skeleton including a backbone of vertebrae, even if only rather rudimentary, and a skull. The notochord does not extend to the front of the head, and is reduced or absent in the adult. They have a well-developed brain and heart, and usually two pairs of limbs.

Class: **Pisces** (Fish). These are aquatic animals and cold-blooded; their temperature is almost the same as the medium surrounding them and varies with it. They possess gills and paired fins. The bodies are covered with scales.

Class: **Amphibia.** These also are cold-blooded. They have gills only in the larval stage. They possess paired pentadactyle limbs. The bodies are not covered with scales.

Class: **Reptilia.** Cold-blooded, with pentadactyle limbs, and bodies covered with epidermic scales. The gill slits have

no gills even in the embryo. They lay eggs with calcareous shells. The embryo is supplied with an allantois for respiration, and is enclosed in an amnion. Reptiles are represented in England by snakes and lizards. We give below some details of English lizards. There are three **British lizards,** the common lizard (*Lacerta vivipara*), the sand lizard (*L. agilis*), and the slow-worm (*Anguis fragilis*). The lizard's body is close to the ground because its limbs are short; and a distinctive character is its tail, which is as long as the head and body (Fig. 384). It can run rapidly and nimbly, and also shoot from one patch of vegetation to the next, the long, slender fingers and toes securing it a safe landing. The species *L. vivipara* is found on sandy heaths among the heather, and when all is quiet will emerge to sun itself. In colour it is varying shades of brown with dark spots, and sometimes a blackish band along the backbone. On the underside a male lizard is orange or red with black spots, and the female orange, yellow or green. She may or may not be spotted on the under surface.

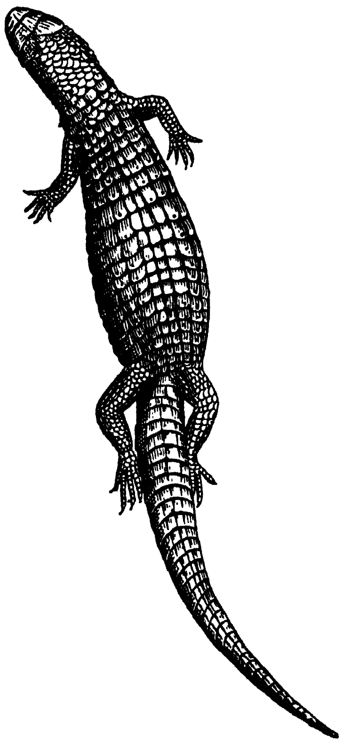


Fig. 384. COMMON LIZARD. (Under side.)

Each limb has five clawed digits. The entire body is

covered with scales. On the upper surface these are small, except those of the head. On the underside of the trunk they are much larger and arranged in six rows, those in the two middle rows being smaller than the others.

Lizards feed upon flies, beetles, moths, spiders, and caterpillars, which are conveyed to the mouth by a broad, rounded tongue, notched at the tip. The jaws are fitted with small conical teeth.

In contrast to most reptiles, the female *L. vivipara* keeps her eggs so long inside her body that the young are born alive, or the covering of the egg breaks immediately. This fact has given rise to the specific name. The mother does not look after the offspring, which are from six to twelve in number. They are about one inch long, and remain motionless where they were born for several days.

Occasionally a tailless lizard may be seen. If the tail is seized the lizard breaks away from it in an effort to escape. It never again grows a tail as long as the original.

The sand lizard is found only in a few localities. It is larger than the common lizard, being on an average seven inches long, while the common one is only five. In this species the female lays about eight eggs.

The slow-worm is called by the ordinary person a snake, because it has no external limbs; but under the skin are vestiges of limbs, and all its structural characters agree with those of a lizard. It is much longer than either of the lizards, the length of the average specimen being about a foot. It is creamy-yellow on the dorsal surface, and very dark below. A dark line runs along the middle of the back and forks into a letter Y at the head. Its favourite articles of diet are slugs. As in *L. vivipara* the young are born alive. These reptiles from time to time cast off their skin, since they grow too big for it.

Class: **Aves** (Birds). These are warm-blooded, so that their temperature is higher than that of their surroundings and remains constant. The limbs are of a modified penta-

dactyle type, the front pair being wings. The bodies are covered with feathers, except the legs which are scaly. The gill slits never have gills. Eggs in calcareous shells are laid. The embryo has an allantois and amnion.

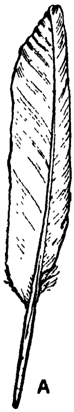
The rock dove, or **rock pigeon** (*Columba livia*), is an example of a typical bird; and all the varieties of domestic pigeon have arisen from it by breeding and selection. As shown

Fig. 385. THE ROCK PIGEON.

in Fig. 385 it has a head, body, and tail. The shape of the body, widest in the middle, is an ideal shape for cutting through the air, just as a similar shape in fishes is an adaptation for movement through water. The body shape is partly due to the covering of feathers, as will be realised by comparing a plucked bird with a live one. The plucked bird has almost no tail, only a very short stumpy piece at

the end of the trunk, and its neck appears very long. The length is disguised in the live bird by the feathers. The neck is very flexible, but the vertebrae in the other regions of the backbone are fixed. On a plucked bird it can be seen that the feathers were not scattered all over the body but arranged in definite tracts, or pterylae, with bare regions, or apteria, between.

Feathers provide a warm, light covering. There are three kinds of feathers. Those that form the general body covering and influence the bird's shape are the contour feathers (Fig. 387). In the wings and tail there are some specially long and strong feathers known as the quills. The smaller that cover the bases of these are called coverts. Contour, quill, and covert feathers all show the same parts, namely a hollow stalk, the quill, and a flattened vane consisting of a solid rod—the shaft—with delicate branches or barbs (Fig. 386). It is very easy to see that the barbs are all united to one another, and a hand lens will reveal the reason (Fig. 386, B). Every barb has barbules branching from it, and the barbules on one side of a barb lie on top of those of its next-door neighbour. The over-lying barbules bear hooks, which catch on to the barbules beneath, these latter having saw-like edges.



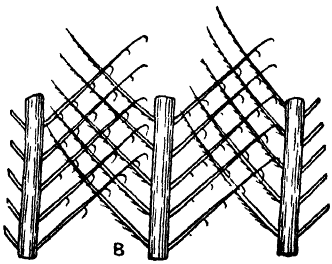


Fig. 386. FEATHERS.

A, Quill feather; B, A small portion of a feather (magnified) showing the barbs and barbules *in situ*.

After the bird has been plucked small feathers, known as filoplumes, still remain. For this reason a bird is singed

after plucking. The body of a young bird is covered entirely with tiny, soft down feathers. Every feather is fixed into a sheath of skin, and each has a growing point at the bottom of this sheath. In the skin of the sheath are muscles, which enable the bird to move its feathers when cleaning itself and when preparing for flight. At the root of the tail is an oil gland, and this produces an oil which prevents the feathers from being wetted.

Fig. 387. A CONTOUR FEATHER.

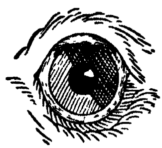


Fig. 388. EYE OF A BIRD. Showing the third eyelid.

The prominent feature of the head is the beak, which consists of the two horny jaws of the mouth. Inside the mouth is a long pointed tongue, but no teeth. In the upper jaw, close to where it joins the head, are two slits—the

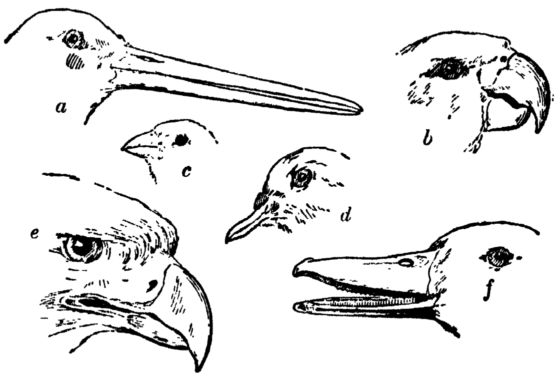


Fig. 389. THE BEAKS OF BIRDS.
a, Stork; *b*, Parrot; *c*, Sparrow; *d*, Pigeon; *e*, Eagle; *f*, Duck.

nostrils. The eyes have an upper and a lower lid and also a third lid (Fig. 388). The ears are not visible as there is no trumpet part: the passage leading to the middle ear is covered by feathers, but if these are pushed aside,

in a region behind and rather lower than the eye, the ear holes can be seen.

Different birds indulge in different diets, and their diet is indicated by the shape of their beaks (Fig. 389). Birds which feed upon worms, such as thrushes, blackbirds, and

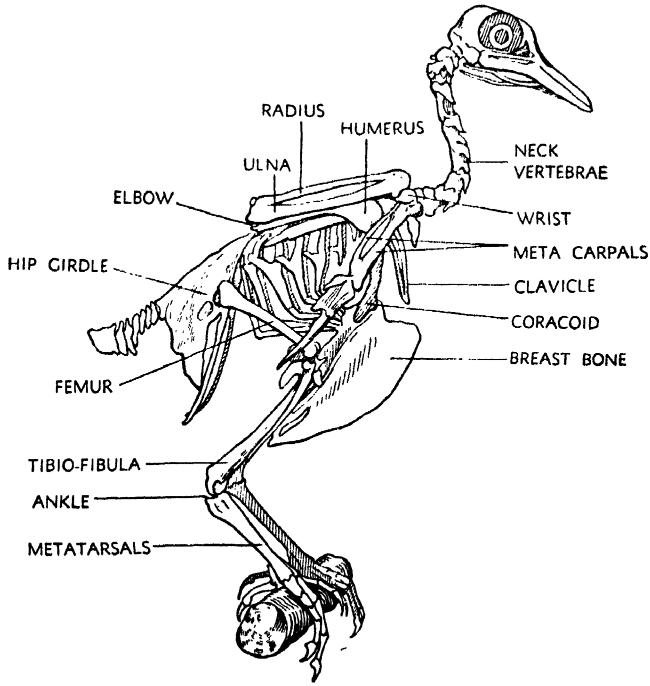


Fig. 390. SKELETON OF THE PIGEON.

starlings, need short, pointed beaks to push into the soil and extricate the worm, and also a beak strong enough to hold the worm. Birds with pointed beaks also have a reputation for being far too fond of the farmer's fruit. Thrushes are very fond of snails. They carry them to a spot where there is a convenient flat stone, upon which

they can smash the shell, prior to extracting the juicy morsel. If you see a stone surrounded by smashed snail shells you will recognise it as a thrush's dining table. The sparrow's short, blunt beak shows it to be a seed-eating bird: the beak is able to crush the hard seeds. Swifts, swallows, and martins have exceptionally short blunt beaks, as they catch tiny insects while on the wing. Their mouths are large, and the beak can be rapidly closed. The duck has a wide, flat beak, in which it can hold worms and insects, while the water drains out. Birds, such as eagles, which feed upon other animals, need sharp, curved beaks for tearing the food.

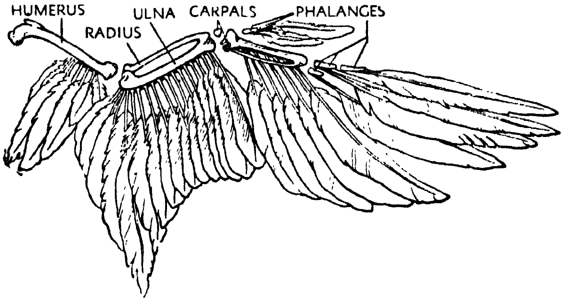


Fig. 391. Bones and Quill Feathers of Bird's Wing.

The legs consist of thigh, shank, ankle, and foot, as in other animals. These parts are shown more obviously in a skeleton limb (Fig. 390). The foot and ankle are covered with scales instead of feathers. Each foot has four toes, which end in blunt claws and have pads beneath them.

At first sight, the wings do not appear to resemble the fore limbs of either the rabbit or the frog because the feathers conceal them. They have, however, bones corresponding exactly with the fore limbs of the other two animals (Fig. 391). The bones of the hand are largely

fused with one another: it is necessary to have a strong support for feathers, not a flexible organ such as is necessary for grasping or walking. There are only two fingers and a tiny thumb attached to the wrist.

Most birds build a nest; in some cases it is an elaborate structure on which much labour and skill are expended by both male and female, while in others it is only a few scraps of material collected together. The site chosen and the material used varies greatly with different

Fig. 392. NEST OF WOOD PIGEON.

birds. The rock pigeon builds an untidy nest of sticks, and in it the female lays two white eggs (note Fig. 392). Each different kind of bird lays an egg with characteristic colouring and marking.

In order that a bird's eggs may hatch, they must be kept at a temperature of 100° F. for several weeks. This is known as incubation, and it is carried out by the mother bird "brooding," that is, keeping them continually covered by her warm body.

In birdland, and in the animal kingdom in general, the male is more handsomely coloured in order to attract a mate, for instance the breast of a male robin is much redder than that of the female.

Class: **Mammalia.** These are the most highly developed members of the animal kingdom, including *Homo sapiens*, man himself. A great advance is shown in brain structure. Mammals are warm-blooded. The bodies are covered with hair, and they have an external ear, which is sometimes very prominent. Internally the thorax is divided from the abdomen by the diaphragm. In most mammals the egg develops inside the uterus so that the young are born alive. In order to nourish the embryo for a sufficiently long period a placenta is formed by the union of the allantois with the uterus wall. The pentadactyle limbs show a variety of modifications according to the mode of locomotion, *e.g.* a horse's hoof for swift movement over hard ground, a whale's flipper for swimming, a bat's wing for flight. Monkeys and apes are able to use their hands and feet to grasp objects.

CHAPTER XXII

SOME FAMILIES OF FLOWERING PLANTS

The two main divisions of flowering plants or Angiosperms, viz. Monocotyledons and Dicotyledons, are further subdivided into a number of families. The number and arrangement of the parts of the flower play a large part in connection with division into families.

1. MONOCOTYLEDONS

In Chapter XIX. some Monocotyledons have been described. The perianth and parts of the flower arranged in whorls of 3 are indicative of **monocotyledons.** Plants of this group will have parallel veined leaves, and scattered bundles without cambium in their stem. The flowers of Lilies (*Lilium*), Tulips,

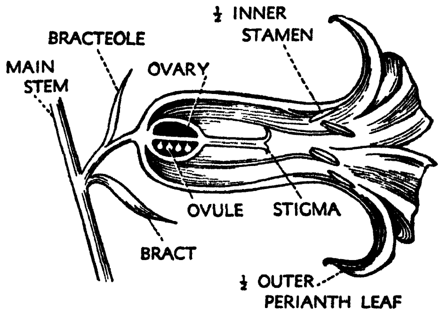


Fig. 393. BLUEBELL. Half-flower.

Hyacinths, and Bluebells (*Scilla*) have the same number of parts and a superior ovary. They are placed together in a family known as **Liliaceae.** Fig. 321 shows a median vertical section of a lily, and Fig. 322 its floral diagram. The floral formula being: $\oplus\ \{P3 + 3\ A3 + 3\}\ G(\underline{3})$. Fig. 393 shows a half-flower of bluebell. When special leafy structures occur on the flower stalk close to the flower they are called bracteoles. When the perianth leaves are joined

to make a perianth tube as they are in hyacinth, they must be shown joined in the floral diagram, as in Fig. 394, and the formula will be: ⊕ {P(3 + 3) A3 + 3} G($\underline{3}$).

The British genera are nearly all herbaceous with underground perennating organs. Smilax is a climbing plant. Butcher's Broom (*Ruscus aculeatus*) is a shrub in which the leaves are reduced to small scales and the lateral branches known as cladodes are flattened to resemble leaves (Fig. 395). These are vertically placed and as the direct sun strikes only the thin edge much less water vapour leaves their surface than would do from

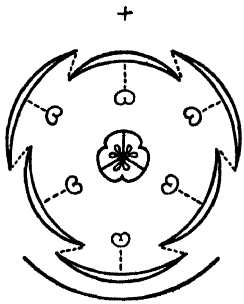


Fig. 394. FLORAL DIAGRAM OF HYACINTH.

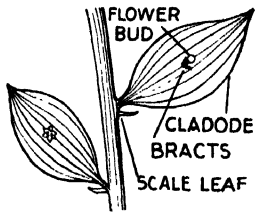


Fig. 395. BUTCHER'S BROOM.

leaves placed horizontally. In the centre of the cladode is a bract in the axil of which the flower develops. The fruit in this family is either a capsule or a berry.

2. DICOTYLEDONS

A. APETALAE

The primary divisions of the Dicotyledons are based on the petals. Many trees have inconspicuous wind-pollinated flowers, with either stamens or carpels, and produced in inflorescences known as catkins. As they possess no petals they are placed in the **Apetalae**. Examples are Poplar, Oak, Hazel, Alder.

B. POLYPETALAE

In the members of the Polypetalae the petals are free. The families are further grouped according to the position of the ovary.

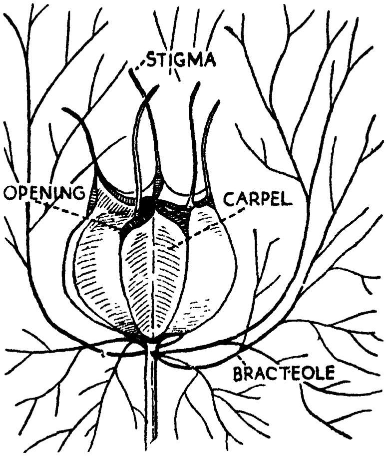


Fig. 396. FRUIT OF NIGELLA.

1. RANUNCULACEAE

The family Ranunculaceae, to which buttercup (Chapter XX.) belongs, has free petals and a superior ovary. The plants in this family are herbaceous. Their net-veined leaves have sheathing bases. Clematis is a climbing plant. The flowers are characterised further by having all their parts free, and numerous extrorse stamens usually showing a spiral arrangement. The fruit is usually compound being a group of achenes or follicles. In Nigella the carpels resembling follicles have become loosely united in the centre thus producing a capsule (Fig. 396). In this family there is great variety of form and colour because the flowers are adapted for pollination by a variety of insects. Many of the flowers are shallow and open, and can be pollinated by flies and bees. In some cases the sepals are the attractive part, and the petals are small, inconspicuous, tubular nectaries, e.g. *Hellebore* (Fig. 397). The formula for this flower is: ⊕K5C*about* 10A∞G*about* 5.

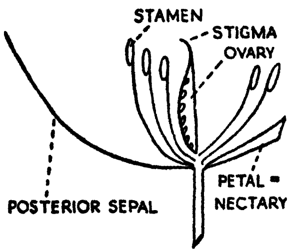


Fig. 397. MEDIAN VERTICAL SECTION OF HELLEBORE.

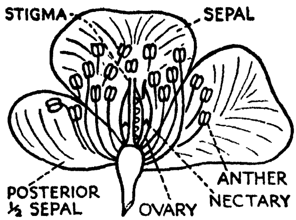


Fig. 398. HALF-FLOWER OF KINGCUP.

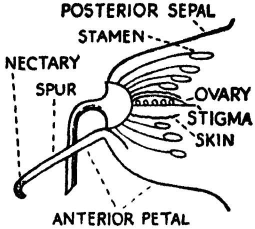


Fig. 399. MEDIAN VERTICAL SECTION OF AQUILEGIA.

Similar nectaries occur in some species of **anemone,** in some the petals are missing. In *Ranunculus* the nectary is at the base of the petal (Figs. 341 and 343). In *Caltha* the nectaries are little pockets on the ovaries (Fig. 398).

Other flowers have the nectar at the end of a long tube so that only bees and other long-tongued insects can reach it, e.g. *Aquilegia* (Fig. 399) and *Delphinium* (Fig. 400). In Aquilegia the flower is actinomorphic, each petal being spurred (Fig. 401). Delphinium is zygomorphic, only the two posterior petals having spurs containing nectar, the two other petals are hairy and placed at the entrance to the spur. They protect the anthers and stigmas from wet,

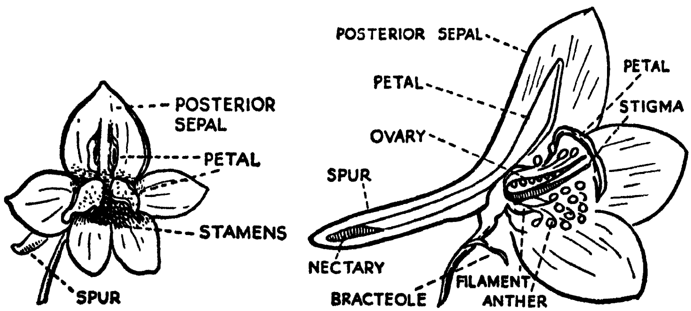


Fig. 400.
FRONT VIEW OF DELPHINIUM. HALF-FLOWER OF DELPHINIUM.

help to provide a platform for the visiting insect and prevent small insects from crawling down the spur and not effecting pollination. In Monkshood (*Aconitum*) the two posterior petals have a curious form (Fig. 402) and unusual position. The formula for this flower is $\swarrow K5\ C5{-}8\ A\infty\ \underline{G1{-}5}$. A floral diagram is shown in Fig. 403. These flowers are visited and pollinated by humble bees.

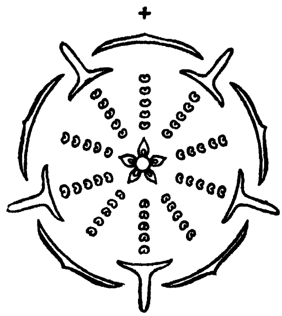


Fig. 401. FLORAL DIAGRAM OF AQUILEGIA.

Most flowers of this family are protandrous, and the pollen is scattered on the underside of the insect. Hellebore is protogynous, that is the stigmas are ready to receive pollen before the anthers in the same flower have dehisced.

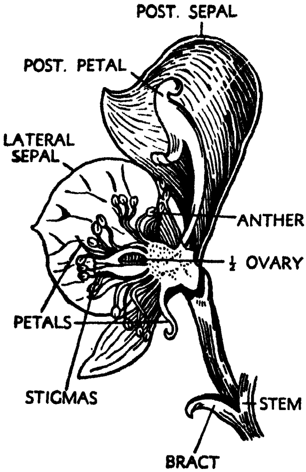


Fig. 402. LONGITUDINAL HALF OF FLOWER OF MONKSHOOD.

2. LEGUMINOSEAE

Leguminoseae is another family in the Polypetalae group with a superior ovary. It includes a great many herbaceous plants of economic importance, *e.g.* peas and beans (see Chapter XX.), clover, bladder senna, as well as some shrubs, *e.g.* gorse (*Ulex*), broom (*Cytisus scoparius*), and trees, *e.g.* laburnum (*Cytisus laburnum*).

Members of this family all form a symbiotic association between their roots and nitrogen-fixing bacteria (see

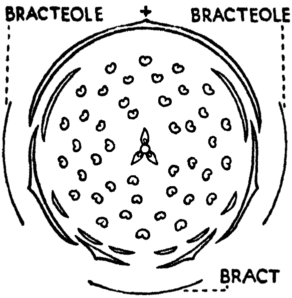


Fig. 403 (*a*). Floral Diagram of Monkshood.

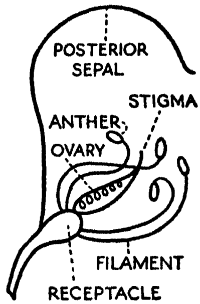


Fig. 403 (*b*). Median Vertical Section of Monkshood.

Chapter XXX.). The leaves are stipulate, in many cases compound. The terminal leaflets may be modified to tendrils, e.g. *Pisum* and *Lathyrus*.

All the British members of this family have the characteristic form (Figs. 347 and 348), and number of parts exemplified by peas, $\swarrow$ K(5) C5 A(5 + 4) + 1 $\underline{\text{G}1}$ (Fig. 344), or beans, $\swarrow$ K(5) C5 A(10) $\underline{\text{G}1}$ (Fig. 404). Many of them are self-pollinated, but marked protandry often gives a good opportunity for cross-pollination. They are visited by bees. In broom the keel is suddenly depressed and the stamens and stigma fly out (Fig. 405). The original positions of the parts are not resumed. In clover and laburnum the stamens and stigma spring out when the keel is depressed, but all the parts return to their former position when the insect leaves the flower; so that further visits are possible. Lupin has the keel petals joined along the posterior side as well as the anterior, and the pollen is squeezed out of a small

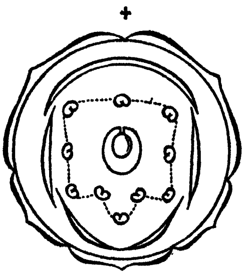


Fig. 404. Floral Diagram of Bean.

hole at their tip (Fig. 406). Five stamens are definitely longer than the other five, and have their filaments enlarged at the top to force out the pollen which has been shed into the keel. Later the stigma protrudes when the keel is depressed. Self-pollination frequently occurs as the keel returns to its position.

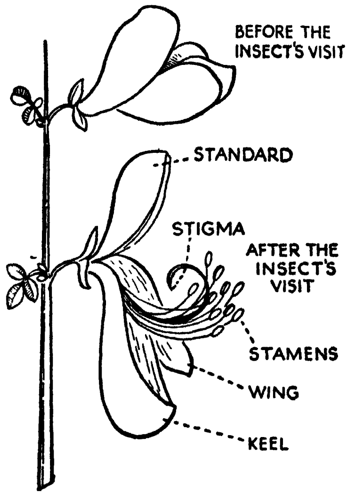


Fig. 405. Broom—to Show Pollination.

The family receives its name from the fruit which is a legume (Fig. 351). In gorse the dehiscence is explosive, and the halves of the fruit roll up after they have separated. In bladder senna the pods are inflated for wind dispersal.

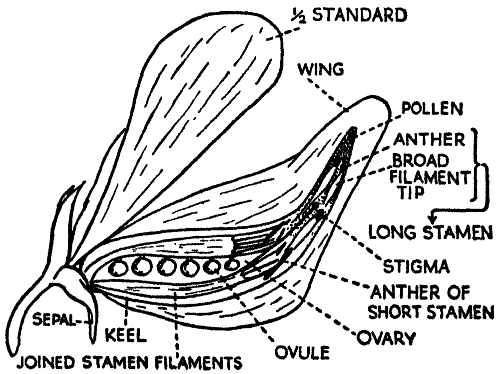


Fig. 406. Half Flower of Lupin.

3. UMBELLIFERAE

This family differs primarily from Ranunculaceae and Leguminoseae because the ovary is inferior.

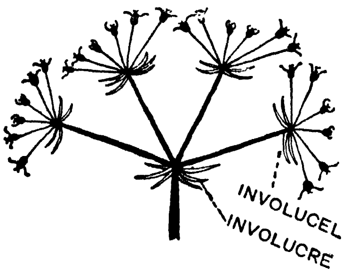


Fig. 407. A COMPOUND UMBEL.

This family includes the many varieties of parsley, celery, parsnip, chevril, hemlock, fennel, and many plants used in pharmacy. Most of the plants are herbaceous with ribbed, hollow stems. The leaves are arranged alternately; they have large sheathing bases, and the lamina is usually very much divided.

This family receives its name from the inflorescence which is usually a compound umbel (Fig. 407), although simple umbels do occur, e.g. *Astrantia*. The flowers are usually small and white, occasionally yellow, *e.g.* fennel. They have the formula ⊕ K5 or o C5 A5 $G(\overline{2})$. On top of the ovary is a conspicuous honey disc (Fig. 408). They are visited by short-tongued insects, especially flies and beetles. The flowers may be unisexual. They may have the petals which come on the outside of the inflorescence larger than the others, making those florets zygomorphic. The ovary has two loculi, one from each carpel, and there is one pendulous ovule in each (Figs. 408 and 409).

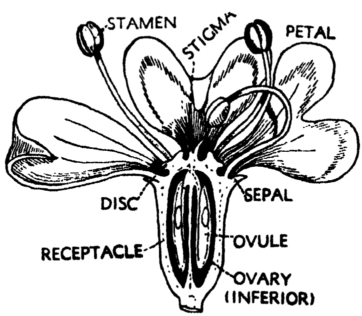


Fig. 408. VERTICAL HALF OF FLOWER OF COW PARSNIP.

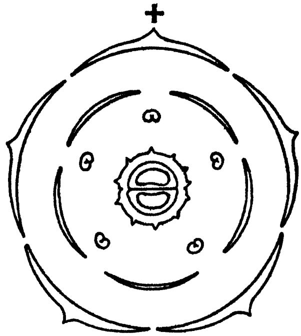


Fig. 409. Floral Diagram of Umbelliferae.

The fruit of this family is characteristic because it splits into two one-seeded parts (Fig. 410). Fruits which split in this manner are called schizocarps, and the parts into which they split mericarps. In this case the split is longitudinal and between the carpels in such a way that the mericarps remain attached for a time by very delicate "stalks," from which they will probably be removed later by the wind. Each mericarp is usually marked with five longitudinal ridges containing vascular bundles. In the furrows between the ridges are oil ducts, in consequence of which some of the plants in this family have gained some economic importance.

C. Sympetalae

In this group the petals are joined, and as in the Polypetalae the ovary may be superior or inferior.

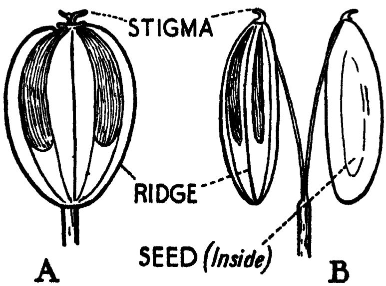


Fig. 410. Fruit of Cow Parsnip (*Hieracleum*).
A, Whole. B, Separating.

1. SOLANACEAE

Solanaceae has a superior ovary. This family consists mainly of herbaceous plants, amongst which is the potato with its edible stem tubers, the tomato with its edible fruits, and many which have medicinal value, *e.g.* Atropa

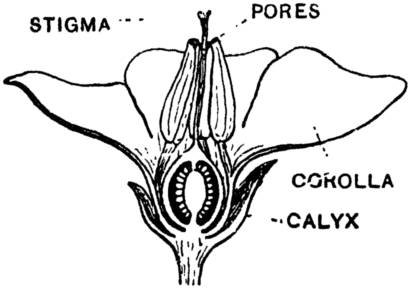


Fig. 411. Vertical Half of Flower of Solanum Tuberosum.

Belladonna, which yields atropin, the active principle in belladonna. There are some climbers, *e.g.* woody nightshade (*Solanum dulcamara*), in this family.

The leaves are alternate, exstipulate, simple, but often have a somewhat divided lamina. The inflorescence is usually a cyme. The floral formula is: $\oplus$ K(5) {C(5) A5} $\underline{\text{G(2)}}$. Fig. 411 shows a very characteristic way in which the large orange anthers stand up closely round the style. Fig. 412 shows another form. For examination of the transverse section the ovary should be retained in the calyx with the posterior sepal marked, because the carpels are placed obliquely (Fig. 413). The axile placentas are usually swollen and bear numerous ovules. The ovary sometimes becomes multilocular by the growth of false

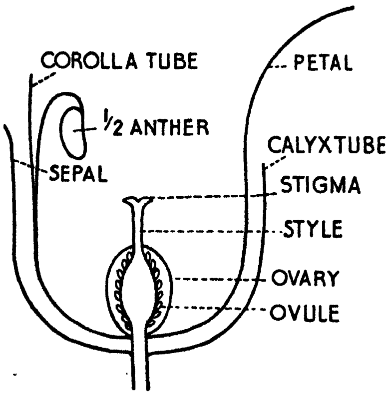


Fig. 412. Medial Vertical Section of Atrope Belladonna.

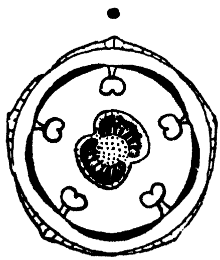


Fig. 413. Floral Diagram of Solanum.

partitions. This is often seen in tomatoes. The fruit is either a berry or a capsule.

2. COMPOSITAE

This is one of the largest and most widely distributed families. The essential characters of this family are seen in Daisies (Chapter XX.). The capitulum is the inflorescence of the family. Each floret has joined petals and an inferior ovary. The florets may be tubular in the centre surrounded by ligulate ones as in daisies, sunflower, some chrysanthemums, they may be all ligulate, *e.g.* dandelion (*taraxicum*) (Fig. 414), or all tubular, *e.g.* cornflower (*centaurea*) (Fig. 415).

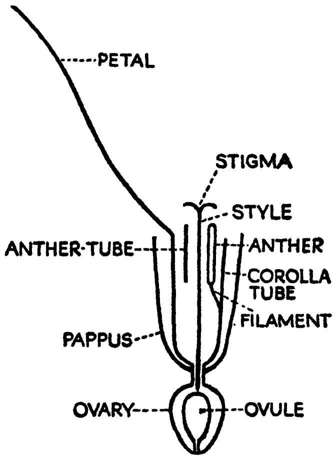


Fig. 414. MEDIAN VERTICAL SECTION OF DANDELION FLORET.

The individual florets may have either stamens or carpels or both, or they may be sterile. The capitula exhibit considerable division of labour. In the majority of cases the calyx of each floret forms a pappus (Fig. 416), for the wind dispersal of the fruit which is a cypsela; so that after the flowering stage the capitulum later appears a fluffy mass.

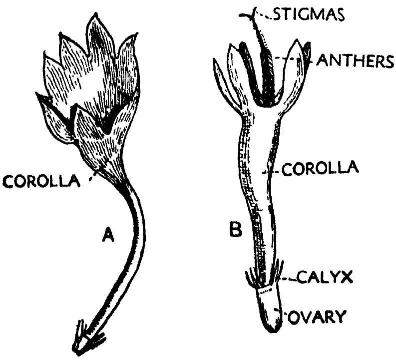


Fig. 415. CORNFLOWER (CENTAUREA). A, Outer neuter flower; B, Tubular hermaphrodite flower. (Both sexes present.)

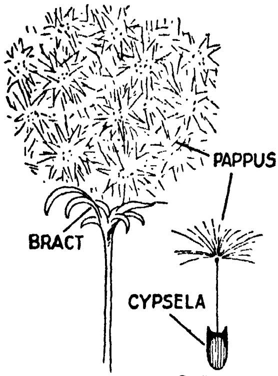


Fig. 416. DANDELION CLOCK.

Families described in this chapter may be summarised:

A. ANGIOSPERMS

I. *Monocotyledons*

Liliaceae $\oplus \{P3 + 3\ A3 + 3\}\ G\underline{(3)}$

or $\oplus \{P(3+3)\ A3+3\}\ G\underline{(3)}$.

II. *Dicotyledons*

B. POLYPETALAE

(*a*) Ovary superior.

(1) Ranunculaceae. $\oplus$ or $\swarrow$ K5 or more Co, 5 or more $A\infty\ \underline{G1-\infty}$.

(2) Leguminoseae. $\swarrow$ $K(5)\ C5\ A(5+5)\ G\underline{1}$

or $\swarrow$ $K(5)\ C5\ A(5+4)+1\ G\underline{1}$.

(*b*) Ovary inferior

Umbelliferae. $\oplus$ Ko or 5 $C5\ A5\ G\overline{(2)}$.

C. SYMPETALAE

(*a*) Ovary superior

Solanaceae. $\oplus\ K(5)\ \{C(5)\ A5\}\ G\underline{(2)}$.

(*b*) Ovary inferior

Compositae. When complete floret

$\oplus$ or $\swarrow$ K pappus $\{C(5)\ A(5)\}\ G\overline{(2)}$.

May be sterile, without pappus, staminate, or pistillate.

CHAPTER XXIII

CONSTITUENTS OF A PLANT BODY

1. WATER

If any part of a plant, even an apparently dry seed, be heated in a test-tube, water will be deposited on the inside of the cool upper part of the test-tube. This compound, consisting of the two elements hydrogen and oxygen, is continually taken in at the root, and is always present in all parts of any plant. The quantity present in any particular part can be accurately determined.

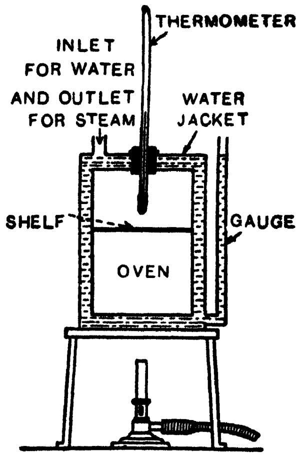


Fig. 417. SECTION OF WATER OVEN.

EXP. Chop the plant material into fairly small pieces, weigh them and put them into a weighed crucible or evaporating dish, and leave in a water oven (Fig. 417) at a temperature of 100° C. for twenty-four hours or longer. Re-weigh the dish and its contents. There will be a loss in weight because water will have been driven out of the plant material. Return the dish to the oven and after a further period of heating, reweigh. If the weight has remained the same it follows that all the water was driven out of it in the first place, but if it has altered the second heating must have driven off more water. The heating must be continued until two consecutive weighings are the same. This will mean that the material has lost all the water that it originally

contained. By subtracting the weight of the dish from its weight plus the dried contents we have the **dry weight** of the plant material, and we can work out the percentage amount of water that it held. Leaves contain the highest percentage and dry seeds the lowest.

2. CARBON AND ASH

When plant material is heated in a test-tube it blackens. This proves the presence of the element carbon, familiar to us in the form of soot and lamp black.

Exp. Heat the dry plant material, obtained in the previous experiment, strongly in a weighed crucible. It blackens and catches fire. The carbon gradually burns away and when it has all gone no blackness remains, only a white ash. By reweighing the crucible and ash the amount of carbon that has burned away is determined, and the percentage present in the dry plant material calculated. It will be found to be very high, round about fifty per cent., so that the bulk of a plant's dry weight is carbon which has been obtained from the atmosphere in the form of carbon dioxide. (See Chapter XXV.)

Ash can be chemically analysed, and is found to contain nitrates, sulphates, phosphates, chlorides, magnesium, iron, calcium, sodium, and silicon. It consists, in fact, of mineral salts, which can also be found in soil. These have been taken in by the root hairs in solution from the soil (Chapter XXV.); and the chemical elements nitrogen, sulphur, phosphorus, potassium, magnesium, calcium, iron are necessary if a plant is to grow normally and healthily (Chapter XXV.). They are used for building up the following substances and the whole plant body.

3. CARBOHYDRATES

These are compounds consisting of the elements carbon, hydrogen, and oxygen. The number of atoms present of

the two last named are in the proportion hydrogen : oxygen 2 : 1, as in water. The material cellulose, which composes the cell walls, is a carbohydrate, and so also are starch and all the various forms of sugar. If any of these substances are heated water is given off, and they blacken, showing the presence of carbon.

CELLULOSE.—Cotton wool, which occurs inside the fruits of the cotton plant to bring about dispersal of its seeds by wind, is almost pure cellulose. If it is dipped in Schulze's solution (chlor-zinc-iodine) it becomes blue. The same result is obtained by putting it first in iodine and then in dilute sulphuric acid.

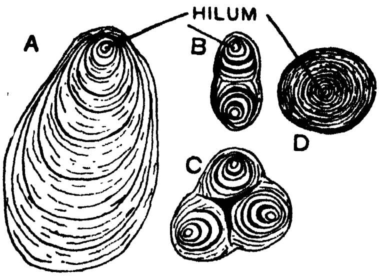


Fig. 418. STARCH-GRAINS.
A, Excentric; D, Concentric; B, C, Compound.

STARCH.—This can be mixed with water, but does not dissolve, and settles out again when left standing. If mixed with boiling water or boiled in water, it makes a jelly-like paste. It can easily be detected by means of iodine, which produces a dark blue colour. Tincture of iodine, which is iodine dissolved in alcohol, or iodine dissolved in potassium iodide, is generally used for this test, and may be applied to the solid starch, its mixture with water, or to the paste.

Starch occurs in a plant in the form of **grains**, and these are often easily visible under the microscope, especially in parts where it is stored. They have a shining, white appearance, and a little iodine drawn under the coverslip makes them blue. Potato contains large starch grains, and if a transverse section of it be examined under the high power of the microscope some of the grains will show their structure.

They are oval in outline, and at the narrower end of the oval there is a dot, the hilum. This is surrounded by concentric, oval lines (Fig. 418, A). The hilum was the beginning of the grain, and the lines are lines of growth. Occasionally several grains are seen enclosed in a common sheath, and these are compound starch grains (Fig. 418, B, C). If a Pea seed be soaked in water, and sections taken of the cotyledons, starch grains are again visible. They are round instead of oval (Fig. 418, D). Starch grains of Potato may be described as excentric, and those of Pea as concentric. Rice grains soaked, crushed, and mounted on a slide show very small, polygonal starch grains.

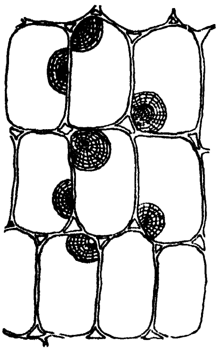


Fig. 419.
CELLS WITH INULIN-CRYSTALS.

INULIN.—This is a carbohydrate present in the under-ground parts of a few plants. It is soluble in water. If alcohol be added to the solution a white precipitate is formed. If sections of a Dahlia tuber are cut and mounted in methylated spirit or alcohol, crystalline masses of inulin will be seen in the corners of some of the cells (Fig. 419). There are concentric lines in them and also lines radiating across.

TWO KINDS OF SUGAR.—Pure sugar is a white crystalline body, which is very soluble in water. It tastes sweet. If heated very gently water is given off, as in starch, but the sugar very soon melts and changes colour, becoming yellow, then darkening to brown. In this condition it is spoken of as **caramel.** If the heating be continued a smell of burnt sugar results, and the sugar chars, that is, becomes black, indicating the presence of carbon, as in starch. Sugar is thus seen to contain carbon, hydrogen, and oxygen.

Sugar is of more than one kind; that which is obtained from honey and fruits, such as grapes, is called grape sugar, or **glucose.** This can also be obtained as commercial glucose in yellow, irregular lumps.

EXP. Make a solution of glucose and heat it in a test-tube with some Fehling's solution. An orange precipitate is formed, which on continued heating turns red.

Fehling's solution consists of a mixture of equal quantities of two liquids, one blue and the other colourless. The blue one is copper sulphate dissolved in water. The colourless one is a solution of Rochelle salt and caustic soda. The blue copper sulphate is reduced to red copper oxide by the action of the sugar. For this reason glucose is called a **reducing sugar.**

Sugar which is obtained from the sugar cane and beetroot is known as **cane sugar.** If a solution of this be treated with Fehling's solution no change of colour results. This is therefore called a **non-reducing sugar.** Thus there are two kinds of sugar.

EXP. To determine that cane sugar is present, the solution should be boiled for a few minutes with dilute hydrochloric acid. This causes the cane sugar to be changed to a reducing sugar. The acid remaining must be neutralised by adding caustic soda. Then add Fehling's solution as before, heat, and the precipitate will be produced as above, yellow changing to red.

STARCH MAY BECOME SUGAR.—The insoluble substance starch becomes soluble sugar in the process of digestion, or its preparation for use by a living plant. This change is brought about by an **enzyme** known as **diastase.**

Barley seeds, when soaked and allowed to germinate for a few days, produce diastase, which can be obtained in solution by crushing the barley with a small quantity of

water, and filtering. A similar solution of diastase can be obtained by taking some green leaves in the summer and crushing them in water. Diastase can also be bought as a cream-coloured powder.

Exp. Some starch paste should be made, to this a solution of diastase added, and the mixture kept in a warm place for a few days. A one per cent. solution of starch paste will give a quick result. It is a good plan to have several test-tubes containing the mixture, so that one can be tested at intervals, or increasing quantities of diastase may be put into them. One test-tube must contain starch only, so as to form the control. Take a little from the test-tube containing starch only and from one or more of the others. To each of them add a little iodine solution. Where the diastase has been strong enough and has had sufficient time to change the starch, the blue colour will not appear.

To another portion of the solution in which some or all of the starch seems to have disappeared, add Fehling's solution, and heat. A red precipitate will be produced, indicating the presence of glucose. If the control starch paste be treated with Fehling's solution no change will take place.

These experiments show that the starch has, in the presence of diastase, been changed into glucose. Diastase is an example of a large group of substances called enzymes, all of which are capable of causing a chemical change to occur without in any way altering themselves. A small quantity of an enzyme can cause change in a large amount of material. Since the enzymes do not change themselves, they are similar to the catalysts sometimes used to cause chemical reactions to occur. Enzyme activity depends very definitely upon the concentration of materials present in the cell. The action is also characterised as being a reversible one. When sugar is being made in plants and the concentration reaches a

certain value in the living cell, diastase converts some of the sugar into starch, thus reducing the concentration. When no sugar is being made and substances in the cell are being used, so that the concentration in the sap is reduced, diastase converts some of the starch, if there is any present, into sugar. In this way a suitable concentration for maintaining the activity of the protoplasmic content of the cell is maintained.

If a test-tube containing starch and diastase is heated to a temperature of about 60° C. or more, the starch remains unchanged because the heat has destroyed the enzyme. Enzymes are complex organic substances with large molecules, which rather readily respond to changes in the physical conditions.

4. PROTEINS

The muscles of animals, familiar in the form of raw meat, and white of egg, both consist almost entirely of proteins. There are also many different proteins in plants. They are compounds consisting of carbon, hydrogen, oxygen, nitrogen, sulphur, and some phosphorus may be present. The protein present in nuclei contains phosphorus. As obtained from the raw egg it is a rather thick, sticky, clear liquid. If the egg be boiled it becomes a white, soft solid. On gently heating in a test-tube it will blacken, showing the presence of carbon, and a smell like burning feathers will result, which shows that a further and different substance is present. This new substance is nitrogen.

EXP. Mix some very small pieces of the solid white of egg with soda-lime in a crucible and heat strongly. Fumes will arise, and a smell of ammonia can be noticed. The presence of ammonia, and therefore nitrogen, can be shown by taking a moistened red litmus paper and holding it above the crucible, in the fumes, when it turns blue, showing the presence of alkaline fumes. The same change

in litmus occurs when a solution of ammonia is used. A further proof is obtained by taking a glass rod which has been dipped in hydrochloric acid and holding it above the crucible, when the ammonia will combine with the hydrochloric acid, making very white fumes.

EXP. Liquid white of egg is a typical protein. To some of this, in a test-tube, add a little water, then add Millon's reagent, and heat gently. A brick-red precipitate will be produced. To a further portion of the liquid add concentrated nitric acid, and heat gently. A yellowish colour will result. Allow this to cool, then add a little ammonium hydrate, and the yellow colour will change to orange. This is known as the xanthoproteic test.

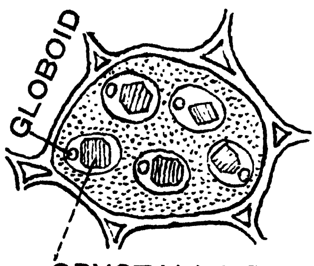


Fig. 420. CELL WITH LARGE ALEURONE GRAINS.

These two reactions show the presence of a substance of the protein class.

Proteins sometimes occur in the form of grains which are visible under the microscope. They are called **aleurone grains,** and are seen to advantage in a Castor Oil seed. This must be softened by soaking, and the grains show well if the sections are mounted in glycerine. Many grains consist of two parts enclosed in a skin (Fig. 420). One part is round and is therefore called a globoid, and the other part, from its angular shape, is called a crystalloid. The latter is protein and the former a double phosphate of calcium and magnesium. Eosine, carmine, or iodine drawn under the coverslip stain the protein.

Tiny aleurone grains also occur in a layer of rectangular cells, called the aleurone layer, just beneath the skin of all cereal grains (Fig. 324).

5. OIL

This is another food substance with very definite properties. A little salad oil, or other oil, if smeared on to a piece of writing paper makes a mark which will remain, and which is more transparent than the rest of the paper. This effect is characteristic of oil and grease. The presence of oil may also be detected by means of osmic acid, which turns it black.

6. SUBSTANCES STORED IN SEEDS AND UNDERGROUND PARTS

Carbohydrates, proteins, and oils are found in seeds, as the food materials for the young plant to use when it begins its independent life in the world.

Seeds, such as Peas, Beans, Maize, Wheat, Rice, Mustard, Cress, may be soaked to soften them, then crushed with water, and the material obtained tested for the food materials as described above. Iodine may show the presence of starch amongst the solid material, and Schulze's solution the presence of cellulose. Fehling's solution will show the presence of glucose. If no glucose be present the material should be tested for cane sugar. Either Millon's reagent or the xanthoproteic test will show the presence of proteins, and the effect on paper or of osmic acid, may indicate oil.

All seeds contain proteins. If starch is present usually some sugar will be there as well. If there is a plentiful supply of carbohydrates there will not be much oil, and vice versa. If any seed be heated strongly, when all the carbon has burned away, a white ash will remain because all seeds contain mineral salts.

In some seeds the foods have a definite distribution. A particularly good example, which shows very distinct areas, is the grain of maize.

Exp. Some grains of Maize should be soaked in water and cut lengthwise through the embryo. Different pieces should then be treated with the reagents used to test for the presence of the foods. (*a*) Add iodine and the starch area will become dark blue. (*b*) Boil with Fehling's solution and the sugar area will become red. (*c*) Boil with Millon's reagent and a very thin red line will be found, showing the presence of proteins.

From this experiment we see that the distribution of food in the grain of Maize is as in Fig. 323. The layer between the part containing the soluble sugar and the insoluble starch produces diastase, the digestive fluid or enzyme, which causes the starch to change to sugar. Other seeds may be treated in a similar way.

Many plants develop swollen underground parts, for example, Carrot, Parsnip, Beetroot, Turnip, Onion, Iris, Sunflower, Daffodil, Crocus, Potato, from which a new plant will develop in the following season. All these parts contain stored food in them, which can be identified by treating them in the same way. A few underground organs also contain inulin, the presence of which is indicated by adding alcohol to a solution, when a white precipitate will appear.

All the stored substances in a plant must be made soluble for the plant's use. This is brought about by means of enzymes, which are present with the food, each class of substance being acted upon by its own enzyme. As stated already starch is converted by diastase. Of the other carbohydrates, glucose is already soluble and suitable for use, but cane sugar is converted by **invertase** into glucose, cellulose is acted upon by **cytase**, and inulin by **inulase**.

Enzymes which act upon fats and oils are known by the general term **lipase**, and an enzyme of this nature is present in a plant where the reserve food is oil. It splits up the oil into glycerol and fatty acids, and as the latter increase

in amount its action takes place more readily. Lipase can be obtained from Castor Oil seeds which have just begun to germinate, by grinding the endosperms in a mortar with five per cent. solution of common salt. The salt can be removed by dialysis; and if alcohol is added to the remaining liquid a precipitate containing lipase results; and this can be separated by filtering.

Where protein occurs in a plant the enzyme **erepsin** is present and changes it to amino acids (Chapter XXV., § 2), or some other soluble form.

CHAPTER XXIV

THE FLOW OF SAP IN A PLANT

1. OSMOSIS

The plant obtains all its food either in a soluble form from the soil or a gaseous form from the atmosphere. If it is a submerged water plant all its food will be derived from the water. In any case water containing dissolved mineral salts plays a very large part in connection with plant food. This enters the root hairs by a physical process known as **osmosis**, and becomes known as cell sap.

Osmosis is the passage of liquids across a membrane. In the case of the root hair there are three membranes, the cellulose cell wall and two plasmatic membranes, separating the solution outside the root hair from the cell sap within it. Osmosis may be demonstrated by means of a **Pfeffer cell.**

EXP. Take a one per cent. solution of copper sulphate and a three per cent. solution of potassium ferrocyanide. With a pipette put a few drops of the potassium ferrocyanide into the copper sulphate. Round each drop a brown covering will form, and this will keep the drop suspended in the solution. This is due to interaction between the two solutions, whereby a membrane is formed. If the drops are carefully watched they will be seen to grow, because water passes into them through the membrane.

For experiment a membrane is needed strong enough to handle; this can be obtained by depositing one inside a small, cylindrical, porous pot. This pot should stand for some hours in the copper sulphate solution until it has soaked through to the inside. If the potassium ferrocyanide solution is then poured in, after about half an hour a brown membrane will have formed inside the pot, and the potassium ferrocyanide can be emptied out. Fill the pot with a strong solution of a salt, push in a one-holed rubber cork carrying a long glass tube, and mark

the level to which the solution rises in the tube. Stand the pot in a beaker containing dilute solution and the level of the solution in the tube will rise (Fig. 421). This shows that the greater flow is from the weak solution to the stronger one.

This apparatus was first used by Pfeffer, and the pot with its membrane was therefore named after him, a *Pfeffer cell.* The porous pot may be compared with the cellulose cell wall, which allows any soluble substance to pass through it. The potassium ferrocyanide may be compared with the plasmatic membranes which exert a **selective force,** because the former will be injured by certain chemicals, and the protoplasm in the latter case, being alive, will use some substances, while others will be quite useless to it and may be even harmful. Only those substances which are used will continue to pass into the living cell. The cell sap corresponds to the solution in the porous pot, the former containing sugars, proteins, and substances with large molecules which will not readily diffuse out of the cell, but will maintain the internal strength needed so that osmosis may continue.

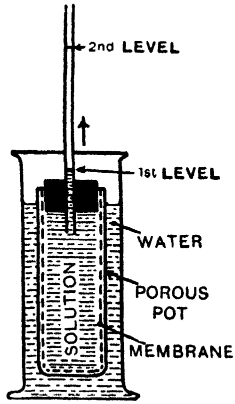


Fig. 421. A Pfeffer Cell.

In soil in which plants grow, each particle of solid substance is surrounded by a film of water, and between these particles the root hairs make their way (Fig. 422), absorbing the water and substances dissolved in it by osmosis. Since the root hairs are living cells it is of fundamental importance that there should not be too much water in the soil, but between the particles surrounded by the water film air spaces should be present, so that respiration may

go on. This respiration has an additional significance because by it carbon dioxide is liberated and dissolves in the water, making carbonic acid. This, although only a weak acid, by its continual presence around the particles, helps to render substances soluble and consequently available to the root hair.

That root hairs do cause the formation of a weak acid around them may be shown by placing a piece of polished marble at the bottom of a flower pot, and then planting in

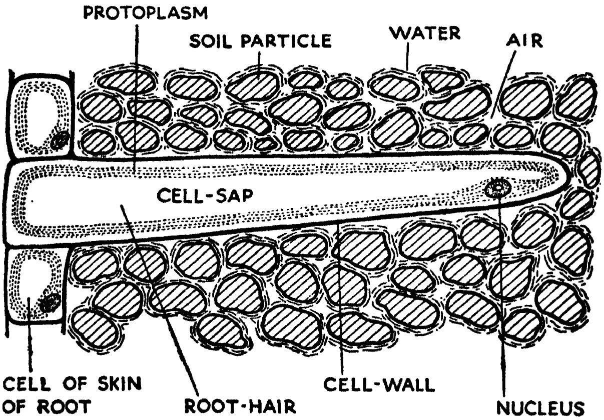


Fig. 422. Root-Hair and Soil Particles.

it some seeds in soil in the ordinary way. When the plants have grown sufficiently, it will be found that the roots have left a little groove in the marble, where they have travelled over it, owing to the acid dissolving the marble. If seeds, *e.g.* Mustard, are germinated on damp blotting-paper in small dishes, and then litmus paper or a weak litmus solution applied, it will be found to give an acid reaction, that is, blue litmus will be changed to red. This should be compared with the colour obtained with blotting-paper and water, without the seedlings.

Osmosis may easily be demonstrated by the following experiment (using plant material):—

Exp. Select a good sound potato of suitable shape, cut the end level, so that it can be stood in a vessel containing water, as in Fig. 423. Peel a small piece at the bottom of the potato. Scoop out a hole from the other end in the centre, taking care not to damage the outside part, which should be quite half an inch thick in all parts. Into the hole put a very small drop of blue copper sulphate solution.

The potato should be placed in water in a beaker and left for some time, when it will be found that the amount of copper sulphate solution in the hole gradually becomes more, until the hole is filled and at length overflows.

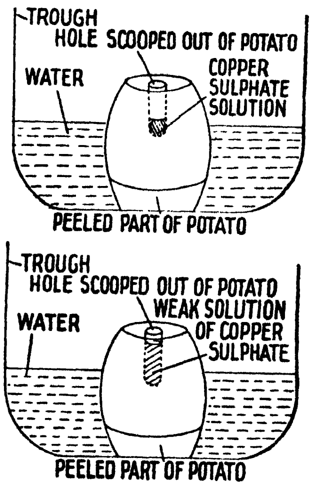


Fig. 423. To Show Osmosis in a Potato.

A turnip, carrot, or other plant organ which can be conveniently handled, can be used instead of a potato. Parts of plants which have coloured cell sap also provide interesting material for osmosis experiments. If the epidermis be removed from Sweet William leaves the cells will be found to have red cell sap. If these are mounted in a dilute solution of ammonium carbonate, the cell sap will gradually become blue. This change in colour shows quite clearly that the ammonium carbonate must have passed through the cell wall and the protoplasm by osmosis.

Sections cut from an uncooked beetroot can be examined microscopically under the influence of different solutions.

When they are mounted in water the thin layer of protoplasm is close to the cellulose cell wall, and the cell appears full of the red cell sap which occupies the vacuole (Fig. 424, A). If the sections be placed in a solution of potassium nitrate, sodium chloride, sugar, or some other substance associated with plant life, no change will be apparent unless the strength of the solution is osmotically greater than that of the cell sap. Should this be the case, water will pass out of the cell in excess of material passing in, and the protoplasm will shrink away from the cell wall, as the amount of liquid in the vacuole ceases to be sufficient to keep it distended (Fig. 424, B). This phenomenon is known as **plasmolysis**. By this method the strength of the solution can be adapted to give greater or less plasmolysis, and the strength can be found which is equal to that of the cell sap, and consequently causes no change in volume. To find this strength a series of observations must be made until two strengths are found very near together, one giving no visible change and one causing a very, very small amount of plasmolysis. The strength **osmotically equivalent** to that of the cell sap may then be considered to be half way between them.

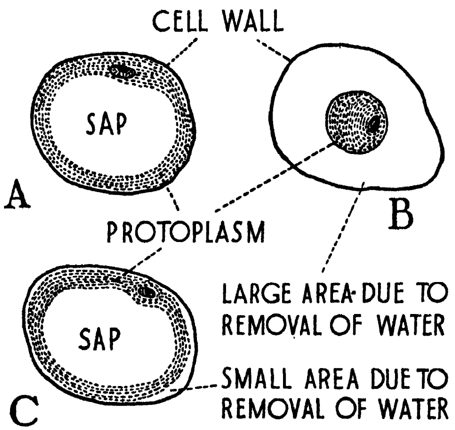


Fig. 424.
A, Normal parenchyma cell; B, The cell plasmolysed; C, The cell very slightly plasmolysed.

When a cell has been plasmolysed by substances such as the above, if placed in water it will be seen to gradually recover again. If the cell has been submitted to the action of a substance like alcohol, or ether, plasmolysis will occur, but the cell will not recover when placed in water, because these substances have not simply been too strong osmotically, but they have injured the plasmatic membranes and protoplasm. In this way substances which are injurious to protoplasm may be discovered.

2. IONS AND IONISATION

All vital processes occur in water, consequently it is tremendously important in connection with life. The molecules of water and salts in solution are known to separate into two parts, each carrying a minute electric charge, one half carrying a positive charge, and the other half a negative charge. These parts are called *ions*, and they play a large part in connection with life processes. Water dissociates into an equal number of hydrogen ions carrying a positive charge and hydroxyl ions carrying a negative charge. These also unite to form molecules of water. This may be briefly expressed thus:—

$$H_2O \rightleftharpoons H^+ + OH^-.$$

When the number of (H +) ions present in a liquid is exactly the same as the number of hydroxyl (OH —) ions the liquid is said to be **neutral.** This condition is obtained in pure water. If there is an excess of (H +) ions the liquid is **acid,** and if there is an excess of (OH —) ions it is **alkaline.** The actual concentration of these ions is very small. Neutral water contains one of each kind of ion in 10 million parts, that is the concentration of each is 10^{-7}. The product of the concentrations of (H^+) and (OH^-) is known as the constant of water, and for the same temperature is always the same, consequently if one is known the other can easily be determined. In practice, therefore, it

has become usual to speak of the H^+ ion concentration. It has also been universally adopted owing to the very small quantities present, and the inconvenience of dealing with figures of that type, that the index of the hydrogen ion concentration bearing a positive sign instead of the negative should be known as the quantity **pH.** Thus the pH of pure water is 7, the H ion concentration being 10^{-7}.

The addition of any acid or alkali immediately disturbs the balance of H ions and OH ions in pure water and alters the pH. An increase in the number of H ions is caused by the addition of an **acid,** accompanied by a corresponding decrease in the OH ions. This means that the H ion concentration is greater than 10^{-7}, *e.g.* 10^{-4}, in which case the pH would be 4. The addition of an acid therefore decreases the pH of the liquid. On the other hand the addition of an **alkali** decreases the H ions and increases the OH ions, and the pH is greater than 7.

The ionisation of solutions, and consequently the changing electrical conditions, plays a very large part in connection with life and life processes. All living processes take place in a medium which is nearly, but seldom quite, neutral. Whether the pH is slightly less or greater than 7 has a very marked effect upon the plasmatic membranes of living cells. It will therefore greatly influence osmosis. The value of the pH of a substance is a very distinct guide to its food value.

3. IMBIBITION

When a dry seed is soaked, water enters the micropyle, and the testa begins to swell in that area. Gradually the testa becomes softened, and the water penetrates through its cells. As the testa absorbs water it increases in size, and thus becomes too large for its contents and therefore wrinkles. After a while the water gets right into the embryo, the cells of which it is composed begin to swell to their full size, and bit by bit the testa is straightened out.

The energy with which seeds absorb water can be shown by filling a matchbox with seeds, *e.g.* peas or beans, and tying the cover on, then submerging it in water. After a time it will be seen that the seeds have burst the box.

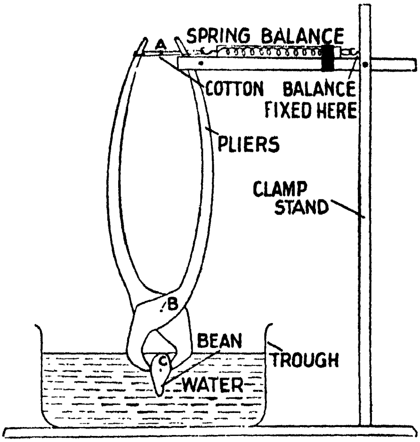


Fig. 425. To Show Pressure Exerted by a Seed when Soaked.

Exp. Place a broad bean seed between the jaws of a pair of pliers, dipping in water, as shown in Fig. 425. Fix one arm of the pliers and fasten the other to a spring balance as shown, adjusting so that the reading is zero. After a time a weight will be registered by the spring balance. Then if the distances **AB** and **BC** be measured, by the principle of a lever, **AB** multiplied by the weight at **A** is equal to **BC** multiplied by the weight at **C**, and from this the weight at **C**, that is the pressure in grammes exerted by the bean, can be calculated.

This energy, which is known as **imbibition**, may also be shown with the apparatus in Fig. 426.

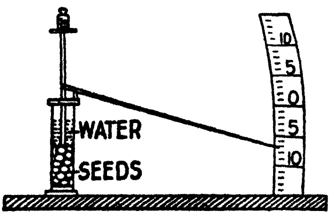


Fig. 426. To Show Imbibition.

Exp. Peas are convenient seeds to use, and about two dozen placed in the cylinder with water will raise a kilogramme weight placed on top. The amount of raising

is magnified by the pointer on the scale, and it can be seen in about twenty to thirty minutes that it is taking place. In a few hours the seeds will be seen to have increased in size considerably.

The process of imbibition is of fundamental importance in connection with all the cells of a living body, the water being absorbed by the colloids present.

Imbibition and osmosis together play a large part in keeping the cells fully distended or **turgid.** They are very important in connection with all the smaller and also the more primitive forms of life; they also help to keep all soft young stems erect, and leaves stiff and firm. The value of turgidity in this connection and the strength of sap needed to maintain it may be seen by taking the stalks of dandelion inflorescences or other similar soft material and cutting off pieces about two inches long, then dividing them lengthwise into strips. These will be seen to curl round with the inner part outermost. If they are placed in solutions of suitable strength they will assume a straight form again, and can be made to curl round the other way. The curling is due to the disturbance of the tensions between the pith and the outer tissues.

4. PATH OF FOOD IN A PLANT

In the simpler plants the food enters by osmosis and passes from cell to cell by the same process. In the higher plants vascular tissues develop to assist in the more rapid passage of sap when it has entered the plant. The path of water inside such a plant may be seen by placing it in water, which has been just coloured with red ink. Only a very small amount of red ink should be used, or the plants may be killed by it. Any seedlings, *e.g.* a Pea, may be placed in this coloured water, and left for a few days. If the root be then cut across, in different places, starting near the tip and continuing to the top nearer the stem, it will

be found that the coloured water, having entered the root-hairs, passes across the soft outer cells to a central cylinder of wood, which it colours red, and up which it travels towards the stem.

Young green shoots of Laurel cut and placed in the coloured water give good results for the passage of water in the stem and leaves. If these are examined after a few days, the woody parts of the veins of the leaves are seen tinged with red; the stem cut across shows the wood coloured red. In a fresh stem cut and dipped in anilin sulphate the parts that have reddened become yellow, because they are wood.

That the wood is the main path along which the absorbed material travels can also be shown in another way.

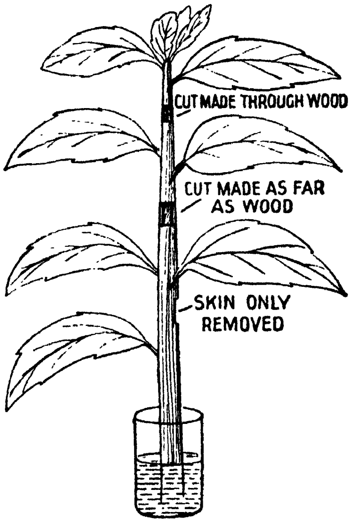


Fig. 427.

Exp. Take a woody branch of laurel, or some other plant, and remove from half its circumference a succession of pieces about a quarter of an inch long, as shown in Fig. 427, and place it in water. In the cut nearest the water remove only the outer covering; in the next, the soft material as far as to the wood; in the third, cut through the wood. Each cut should be made so that a leaf is directly above it. The leaves will receive their supply of water, except those above the area where the wood has been cut through. Above that the leaves will wither, showing that the path of the water supply has now been damaged. This experiment can be done with coloured water if desired.

Willow twigs very readily form adventitious roots in water. From some willow twigs remove the epidermis, cortex, phloem, and cambium, leaving only the wood and pith in this part, then place them in water a little above the ring thus made. After a few days roots will begin to develop above the ring and grow rapidly. In a little while roots will also form below the ring, but they will grow much

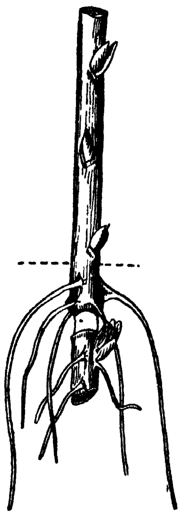


Fig. 428. A Ringed Branch of a Willow Sprouting in Water.

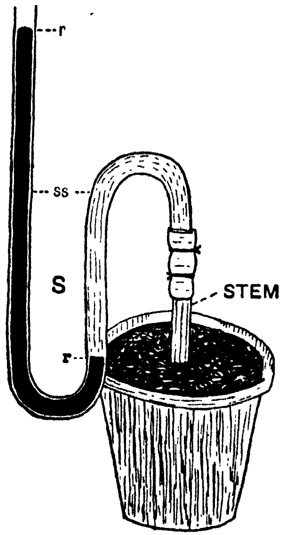


Fig. 429. Apparatus for Measuring Root - Pressure.

more slowly (Fig. 428). This is interesting because it shows that the food material necessary for root development is more readily accessible when the phloem and cortex are present, than when they have been removed.

The sap, having travelled across the cortex of the root, has acquired a force to help it to enter the wood vessels, which

have no living protoplasm in them. This force is known as **root-pressure.** It can be demonstrated as follows:—

EXP. A geranium plant is suitable for this experiment (Fig. 429). The stem should be cut quite near the ground and must be a suitable size for the rubber tubing. It is important that the cut be made and the tubing attached under water, and the root kept watered. The tubing has water in the part next to the plant and mercury in the outer limbs. At the beginning of the experiment the levels of the mercury are equal at *ss*. After a while the mercury is seen to be pushed down in the central limb to *r* and up in the outer limb to *r*. Water has been absorbed by the root and forced out at the cut end, so that the mercury has been pushed up in the outer limb.

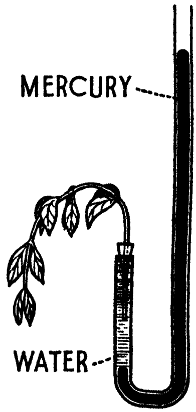


Fig. 430. RESTORING A FLACCID BRANCH.

It is this pressure which causes rapidly growing plants, such as vine, to " bleed " when cut in the spring.

The value of pressure in helping sap to ascend may be shown by allowing a cut branch to become somewhat limp or flaccid, and then fixing it as in Fig. 430. The difference in the heights of the mercury in the two limbs indicates the pressure on the water with which the cut end of the branch is in contact. The greater the pressure which it is practical to exert, the quicker will the leaves, and the branch generally, be restored to their condition of turgidity. When the sap has reached the wood, it is helped to flow mainly upwards towards the top of the plant, whether it is small or a tall tree, by: (1) the structure of the wood, (2) the cohesion of the water molecules, (3) their adhesion to the walls of the vessels or tracheids, and (4) capillarity.

The water having reached the green aerial parts is used to maintain the turgidity of the cells, and in feeding processes, some will vaporise into the air spaces in the mesophyll of the leaves, and from there some will diffuse out through the stomata into the atmosphere.

5. TRANSPIRATION

If a leafy shoot be placed under a bell-jar, or other glass vessel, the inside surface will soon be seen to have become misty, water vapour having been given off from the leaves and condensed on the inner surface of the glass. A small plant in a pot may be used, if the pot and soil are covered over with a mackintosh of thin sheet rubber to prevent evaporation of water from them. A branch in a flask or other vessel, if a layer of oil be put on top of the water, can also be used (Fig. 431). In all experiments where a plant or part of a plant is used, a **control apparatus** in which the plant *only* is omitted must be used for comparison.

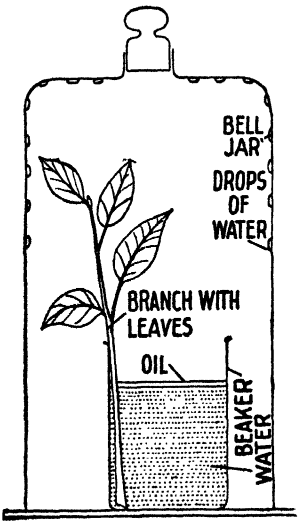


Fig. 431.

This process of giving off water vapour from a plant's surface in the higher plants is largely controlled by the stomata and is known as **transpiration.**

Exp. Cobalt chloride can be used to show the emission of water vapour from leaf surfaces, because it is blue when quite dry and pink when damp. Some blotting-paper should be soaked in a solution of cobalt chloride and then very carefully dried, when the paper will be blue in colour.

Leaves should be placed in pairs on blotting-paper, one with the upper surface uppermost, and one with the lower surface uppermost, then the cobalt chloride paper placed on the leaves and covered over with a piece of glass to prevent the moisture in the air from influencing the cobalt chloride. It will be found that gradually a pink pattern of the leaves appears on the cobalt chloride paper, showing that moisture is being given off by the leaves and changing the colour to pink. If leaves are used which spread themselves horizontally so that they have a distinct upper surface exposed to the sun and a lower surface in the shade, it will usually be found that the lower surface changes the cobalt chloride much more quickly than the upper surface. The times taken to give a complete pattern should be noted. Small pieces of cobalt chloride paper, between coverslips held by paper clips, can be put on leaves attached to growing plants.

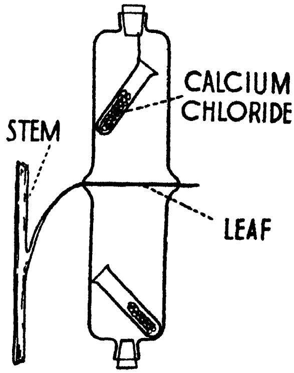


Fig. 432. TRANSPIRATION. From the upper and under surfaces of a leaf attached to a growing plant.

The above is a very simple experiment which shows not only that transpiration goes on, but also that some surfaces give off more water vapour than others. This may also be demonstrated by fixing up the apparatus as in Fig. 432. The weight of the tubes containing calcium chloride is taken at the beginning of the experiment and after a definite interval of time.

If a leaf be taken and placed in hot water small bubbles of air will appear on the surface, owing to the expansion of the air inside the leaf, because the water was hot. These bubbles may be nearly all on one side, the lower side, as in Laurel, and most leaves which assume a horizontal position;

or nearly equally distributed on both sides, as in the Iris, where the leaf is nearly vertical. The bubbles issue through the **stomata.**

A model of a stoma can be made by taking a piece of celery (leaf-stalk), and cutting it lengthwise into thin strips, about two inches long. The strips will curve with the inner part on the outer longer side (Fig. 433, A). Take two of these pieces and tie their ends together, as in Fig. 433, B, so that a pore is left between them, and is bounded by what was the outer surface of the celery. The two pieces of celery represent the guard cells. Whilst they are full of watery sap the pore is open, but if the model be placed in a solution of common salt, some of the water will be withdrawn from the cells of the cut surface, and the pore will gradually close. This corresponds exactly with a stoma; when the supply of water from the root is sufficient, the pore of the stoma is open and transpiration is going on rapidly. If, however, transpiration gets in advance of the supply of water reaching the leaves, the guard cells close the pore, and thus the amount of water vapour given off is reduced.

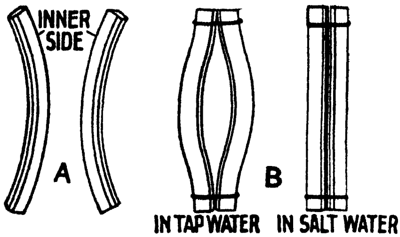


Fig. 433. A Model of a Stoma.

A piece of skin removed from a leaf and mounted on a slide can be treated with water and salt solutions, and their effect upon the guard cells watched microscopically.

Fig. 434 shows a typical stoma in surface and transverse view, together with the latter enlarged to show how the guard cells work. The dotted outline and the shaded protoplasm represent the "closed" position, while the heavy black outline represents the "open" position.

When water enters the guard cells the comparatively thin walls **DC** bulge out into the position **DC′** and pull the points **B** into the position **B′**, thus opening the pore. It is important to realise that the guard-cells of a stoma, like all other cells, have three dimensions, and that in addition to the increased curvature in the plane parallel with the surface of the leaf, they will also become more curved in

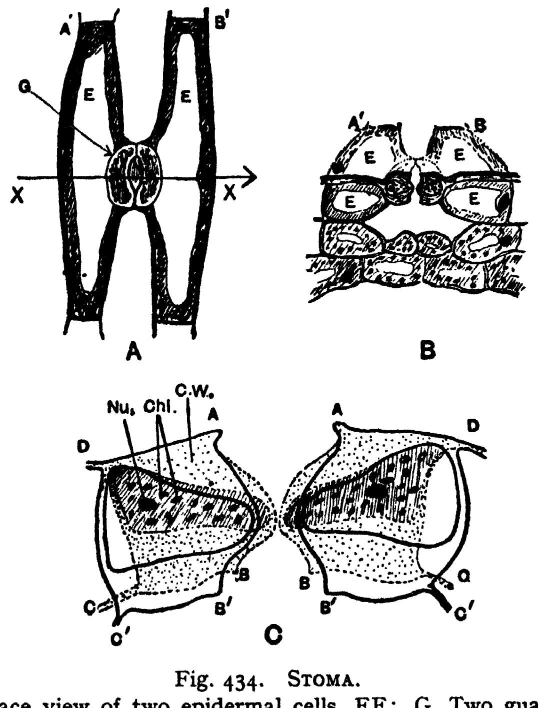


Fig. 434. STOMA.

A, Surface view of two epidermal cells, EE; G, Two guard-cells and a stoma, from an Iris Leaf.

B. Section through the vertical plane XX. (Note chloroplasts in guard-cells.)

C. The two guard-cells in B, further enlarged, to show their action. Nu, Nucleus of guard-cell; Chl, Chloroplasts; C.W., Thick cellulose cell-wall cutinised on the surface.

the direction at right angles to the surface, and therefore bulge a little upwards from their previous surface position, and thus help to open the pore.

Because the guard cells are green they are able to carry on the process of food-building in the sunshine. This building up of food substances increases the strength of the cell sap, and thus helps them to obtain water by osmosis from the cells around. At night, when the sun has gone, this process stops and gradually the guard cells become less full of sap and close, so that transpiration is very much reduced. This gives the plant an opportunity to recover, if it has been hot and dry during the day, so that although it may have got limp, it will be fresh and strong again in the morning.

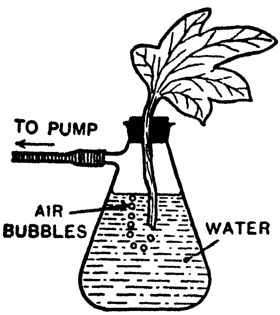


Fig. 435.
Experiment showing continuity of air spaces in plants.

The air spaces which occur between the cells may be shown to be continuous with one another in the leaf and stem. If the apparatus in Fig. 435 be fitted up and some of the air removed from the flask by means of an aspirator or water pump, it will be quite clear that air enters the leaf from the atmosphere, travels in the air spaces, and emerges at the cut end of the stalk. It is important that the leaf should be held quite firmly in the cork and the apparatus should be airtight. A leaf with a large leaf stalk is needed, or a branch tip.

This continuity of air spaces is important to the plant because it enables air to circulate freely inside. The conversion of liquid water to vapour, which occurs in the air spaces, needs a supply of heat. This heat is obtained from the surrounding cells, hence the process of transpiration

keeps the plant cool in warm weather, and will be checked when it is cold.

A direct measure of the amount of water absorbed and given off by transpiration may easily be obtained.

EXP. Set up the experiment shown in Fig. 436. A branch may be used, care being taken that it fits tightly in the hole. To ensure a tight fit, without any damage to the branch, a cork borer, as large as the hole will allow, should be pushed through from the inner side of the cork, and then the branch placed into it and held firmly while the cork borer is removed. If a seedling be used a split cork will be needed, so that the seedling may be placed in the hole by the separation of the two halves. In this case it will be necessary to cover the cork with a thick coat of vaseline or melted paraffin wax.

At the beginning of the experiment the vessel should be quite full of water, and the graduated tube full to the zero mark. After a definite period of time the amount of water absorbed can be read off in cubic centimetres from the fall in the graduated arm. If the whole apparatus be weighed at the beginning and end of the experiment, it will be found to have lost in weight by an amount equal to the weight of the water absorbed.

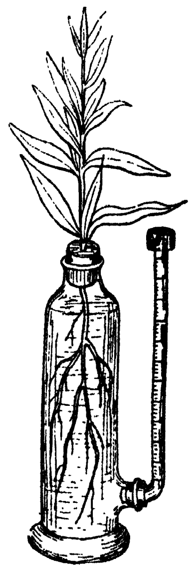


Fig. 436. Apparatus for estimating the absorption of water by the roots, and the loss by transpiration from the leaves.

From this we discover that in a short time the amount of water vapour given off to the atmosphere in transpiration is equal to the amount of water absorbed by the root or stem by osmosis.

Transpiration can be measured by weight. Take a small potted plant and cover the pot and the surface of

the soil with thin rubber, mackintosh, or tinfoil to prevent evaporation. A branch in a beaker of water, with a layer of oil on the surface to prevent evaporation, can also be used. Then very carefully weigh the plant, etc. The amount of water taken in, passing through the plant, and passing out of it into the atmosphere, is so great that in an hour or even less, the plant and the weight no longer

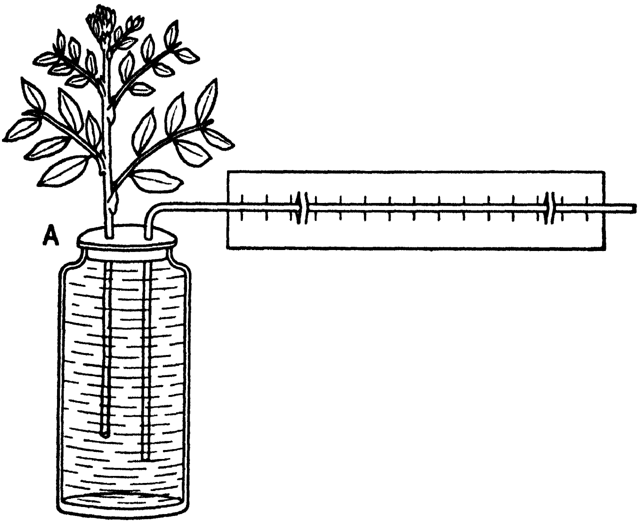


Fig. 437. A POTOMETER.

balance one another. The plant goes on removing the water from the soil or beaker in this way; hence the continual need to water plants in pots and fill up vases containing cut flowers.

When a piece of apparatus is specially designed to measure the *rate* of transpiration it is called a **potometer.** A simple and convenient form of potometer is shown in Fig. 437.

It is important at the beginning of the experiment to see that the apparatus is thoroughly airtight and the branch has not got its skin cracked in the region of the cork. The whole is completely filled with water, to the tip of the glass tube. The distance the end of the water column has moved in half an hour, or an hour, should be noticed carefully by means of the scale placed along the horizontal tube. The volume of water thus removed from the apparatus can be found by direct measure of the quantity of water actually contained in that piece of glass tube, or it can be calculated from the length and the area of the cross section of the inside of the tube.

Measurements of the length alone in a certain fixed time will give comparative rates for different plants and different conditions. The volume of water represents that water which has entered the plant, travelled through it, and disappeared as vapour into the atmosphere in the process of transpiration.

That the rate of transpiration varies under different conditions of the atmosphere may be shown experimentally. Thus that transpiration is more rapid in sunshine than darkness may be shown by setting up two exactly similar experiments as in Figs. 436 or 437, with the same number of similar leaves present. Place one in the sunshine and one in the dark, with the other conditions as nearly the same as possible, and take readings at intervals.

Similar experiments may be performed, placing the potometer in cold and warm, damp and dry situations, in still air and in a windy place. It will be found that heat, dryness, and wind favour transpiration. These conditions are those which cause water to evaporate quickly. The dry air can take up more water vapour than that which is already damp, and a warm air more than cold. When it is windy the air is continually being changed. These external conditions influence the formation of water vapour in the air spaces in the plant and its withdrawal through the stomata.

A series of very simple experiments in connection with the above conditions and their effects upon transpiration can be performed with small branches placed in water in test-tubes. The water must be at the same level in all cases at the beginning of the experiment, and a little oil placed on top of it to prevent evaporation. A comparison of the levels after some time will give the same results as above.

The test-tubes could be suspended from spring balances, and the weights at the beginning and end of the experiment determined, instead of noticing the water levels. This will give the loss in weight due to transpiration in each case. This is a convenient apparatus for demonstrating differences in transpiration in dry and damp atmosphere, because the test-tubes can be placed beneath bell-jars. A damp atmosphere can be created by placing a small dish of water in the bell-jar, and a dry one by enclosing a dish of calcium chloride.

That the stomata are actively concerned with the rate of transpiration can be shown by covering them up with vaseline. Four leaves or branches of equal leaf area should be taken, one being left untreated, one smeared evenly with vaseline on its upper surface, one on its lower surface, and one with both surfaces so covered. The effect on the rate of transpiration of thus closing the stomata can be shown in several ways. The leaves, or small branches of them, can be placed in test-tubes containing water, covered with oil to prevent evaporation. After a time the amount of water absorbed can be determined. Four leaves treated as above, with a little vaseline put on the cut end of the petiole to prevent any escape of water from it, can also be suspended from four spring balances, and after a while the loss in weight determined.

An interesting result of the influence of checking transpiration is seen in the appearance of the leaves, if they are kept for some time. Leaves which have been vaselined on

the under surface, or on both, remain fresh and green in appearance for some time, long after untreated leaves have withered. Laurel leaves are good for these experiments, as they can be hung up as for the spring balance experiment and will last quite a long time. Leaves of the India-rubber plant, *Ficus elastica*, vaselined and hung up in an ordinary room, will remain green and firm for two or three months. When transpiration is stopped, the cells keep their moisture and retain their turgidity.

The rate of transpiration not only varies with the varying atmospheric conditions, but it also must depend upon the availability of water in the particular situation, and the consequent rate of water absorption.

Many of our trees, such as Horse Chestnut, Lime, Oak, are not in any great danger of their water supply running short during the summer months and, consequently, they have large, flat, rather thin leaves, and give off a large amount of the water vapour in transpiration. The same applies to many garden plants, *e.g.* Sunflower, Larkspur, and many plants found in the hedges.

There are, however, many plants which grow in very exposed situations, such as commons and moors, where also the soil is often very dry, and amongst these we find such plants as Heather, which has very small leaves. In these cases only a very small amount of surface is exposed to the atmosphere, and this helps to keep the rate of transpiration low.

Those who have gardens, or the opportunity of visiting gardens, will know that the great majority of rockery plants have very hairy leaves. The effect of the hairs is to prevent the water vapour from escaping too rapidly from the air immediately around the leaves, thus tending to provide them with a damp atmosphere and reduce their rate of transpiration. That hairs do have this effect can be shown by taking two potometers and similar branches; leave one normal and cover all the leaves of the second with

a thin coat of cotton wool and then compare their rates of transpiration.

Some sea-side grasses have cylindrical leaves owing to their being rolled. The leaves are so rolled that the stomata are inside the cylinder. In this case the water vapour collects inside the area enclosed by the leaf and makes it damp, in this way helping to prevent it from giving off more. This also can be shown by means of two potometers, by rolling the leaves of one branch carefully. The leaves should be rolled parallel with their midrib, with the underside in and gently tied round with cotton.

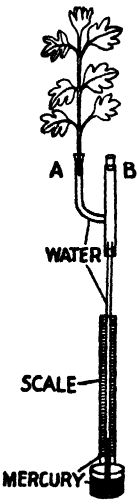


Fig. 438.
To show pull due to Transpiration.

Some leaves, such as Nasturtium (*Tropaeolum*), have a covering of wax on the upper surface; so also have many fruits and flowers. This covering can be sponged or rubbed off, when it will be seen that they wither much more rapidly than those not so damaged. In the case of leaves, it can be shown, with potometers, that the water vapour is given off more quickly from the leaves which have lost their protective covering of wax.

Further examination of leaves shows that they are adapted in many varied and wonderful ways to maintain a state of transpiration consistent with their situation and the dimensions and construction of the other parts of the plant.

The loss of water vapour which takes place in **transpiration** causes an upward **pull** on the ascending sap, to replace that which has been lost. This pull can be shown as follows:—

EXP. The apparatus is constructed as in Fig. 438. The dish contains mercury and the rest of the apparatus

water. The object of the branched tube is to prevent the accumulation of air-bubbles below the cut end of the shoot at **A** (Fig. 438). Any air-bubbles passing up the narrow tube will usually collect at **B**, and the cork is then removed and water poured in. The water is drawn into the plant, and the mercury rises in the tube several inches, sometimes more than a foot.

Since in the above experiment the mercury, which is a very heavy liquid, rose several inches in the tube, it is evident that a good deal of force was required. This force was provided by the transpiration taking place from the green leaves, and external atmospheric pressure.

The water which is taken in by the root and ascends in the wood is continually drawn out of the wood vessels by osmosis into the neighbouring cells. This osmotic pull can be demonstrated by taking a thistle funnel with its end covered with a membrane, as in Fig. 451, filling it with water and placing the end of the tube in a dish of mercury. The membrane will now be at the top, and on to this some calcium chloride can be placed. The calcium chloride is drawing the water from the funnel by osmosis, thus diminishing the pressure in the tube, so that the atmospheric pressure causes the mercury to ascend. The cells in the leaf contain the green colour, are continually manufacturing sugar, and therefore have strong cell sap, so that this osmotic pull will always be exerted. From these cells some water is vaporised into the air spaces, from which it escapes through the stomata in transpiration.

Rapid transpiration is active in helping the sap to ascend. When water is drawn from the wood vessels more quickly than the root can supply it a **negative pressure** occurs in them. That is to say if they are cut across the pressure is found to have been reduced so that air immediately rushes in. This can easily be demonstrated with quickly growing material or on a warm day. Take some leafy material which can be cut at the top, and leave some actively transpiring

branches attached to the main stem below the cut (Fig. 439. This cut and the attachment of the tube must be made under water, to prevent the inrush of air. If the apparatus be fitted up as shown in Fig. 439, the mercury will very soon be seen to rise in the tube, showing how much the pressure in the wood vessels of the main part is reduced by the activity of the adjoining branches. The water from this tube flows in at the top in the opposite direction to the ascending sap.

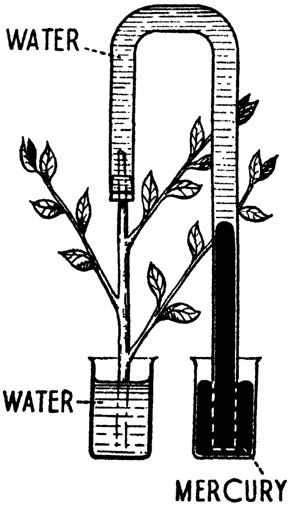


Fig. 439. Experiment to show Negative Pressure.

Some plants, *e.g.* Fuschia and Nasturtium (*Tropaeolum*), in addition to the stomata normally present on leaves, have special pores, known as **water-stomata**, through which drops of *liquid* water are exuded from time to time. Thus at night, when transpiration has been reduced and absorption has been going on, the turgidity of the plant which may have been reduced a bit during the day is restored, and very often in the morning little drops of water can be seen at the ends of veins on the margin of these leaves. These have come out from water pores.

CHAPTER XXV

THE FOOD OF PLANTS

1. FOOD FROM THE AIR

We have already found in Chapter XXIII. that the dry material in a plant body is half carbon. The plant obtains this element from the gas carbon dioxide which is present in the air in a very small proportion, namely 2 to 4 parts in every 10,000. It can be demonstrated that the leaves of a plant take in carbon dioxide.

Exp. Carbon dioxide is liberated by the action of hydrochloric acid on marble, and may be conveniently prepared from these two substances by using a Woulff bottle (Fig. 440). The gas should be led through water to purify it, and then nothing will burn in the gas, so that when the bell-jar is full, a lighted taper held at the mouth goes out. The Woulff bottle can then be removed, and a stopper should be placed in the bell-jar so that it contains only carbon dioxide. The apparatus should be set up four times, once with flowers under the bell-jar, once with the bell-jar empty, and twice with green leaves under it. Three sets should be kept in the light and one of those with leaves in the dark. After several days remove the

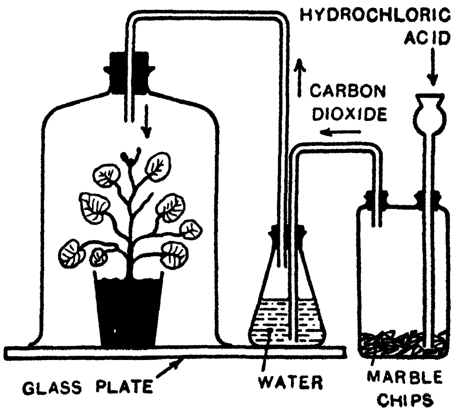


Fig. 440. Experiment to Show that Green Plants Absorb Carbon Dioxide.

stopper and quickly insert a lighted taper into the bell-jar. It goes out in all except the one that contained green leaves and had been in the light. Green leaves in the light must have taken in some of the carbon dioxide and replaced it by a gas that will allow things to burn in it. This is the way in which carbon enters a green plant, *i.e.* it enters in the form of carbon dioxide through the leaves.

It is well known that the breathing of animals and human beings, as well as processes of combustion or burning

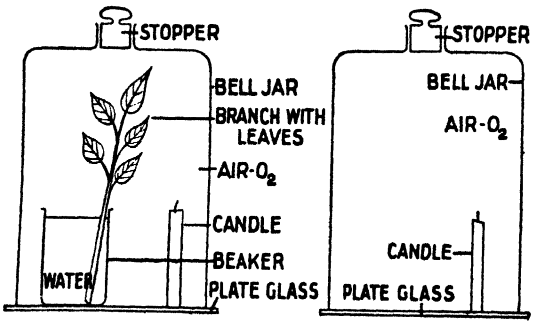


Fig. 441. To Show that a Green Plant gives out Oxygen.

remove the oxygen, and put into the atmosphere in its place carbon dioxide. When enough oxygen has been removed, neither life nor burning can continue, therefore oxygen has been regarded as the vital gas.

The oxygen does not, however, become removed to this extent, in spite of all the life and the uses of coal, gas, candles, and so on, but remains approximately twenty per cent. all the time, because green plants in the sunshine remove the carbon dioxide and restore the oxygen, thus keeping the balance right. This can be shown by the previous experiment, and also as follows:—

Exp. Set up the apparatus as in Fig. 441. At the beginning of the experiment the candle is lit, it burns for a

time then goes out, having used the oxygen in the air in the bell-jar, and put carbon dioxide in its place. If the whole apparatus be placed in the sunshine the green plant will take in the carbon dioxide and replace it by oxygen. That this is so, will be seen by removing the stopper for a moment to relight the candle with a taper, when the candle will burn as before. If no plant be introduced, as in the control apparatus, the air receives no new oxygen. Similarly no new oxygen is supplied if the apparatus be placed in the dark.

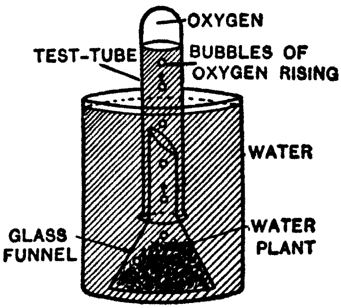


Fig. 442.

The value of parks, open spaces with green grass and trees, also gardens in connection with the health and general well-being of people who live in cities and large towns is obvious from the above experiments. During the daytime the green plant removes the excess carbon dioxide, which is detrimental to animal and human life, and also returns in its place the oxygen, so fundamentally necessary to all life.

The production of oxygen by a plant may be conveniently shown by using a water plant instead of a land plant.

Exps. Take some water plant, such as *Elodea*, in a fairly large beaker and place over it a glass funnel. Then fill a test-tube with water and invert it over the stem of the funnel, which must be below the surface of the water, as shown in Fig. 442. This apparatus should be placed in as sunny a place as possible, when it can be observed that, while the sun is shining, bubbles of gas are forming around the plant, travelling through the water and collecting at the top of the test-tube. It can also be shown that this does not occur when it is dark. The experiment should be

allowed to continue for some days until about half a test-tube of gas has been collected. Then the test-tube must be removed very carefully, by placing the thumb over the open end, and if it be then turned the right way up, a glowing splint can be inserted into the mouth of it. The result will be that the glowing piece of wood will immediately burst into flame, which is a proof that the gas collected is oxygen.

An exactly similar piece of apparatus should be set up and placed in the dark for the same length of time, when it will be seen that oxygen is only liberated when the water plant has sunshine to help it.

A third apparatus should be set up, but using water which has been boiled, so that all the gases present in it have been driven off. The boiled water must be cooled before the water plant is placed in it. In this case also there will be no evolution of gas: the test-tube will remain full of water.

It is interesting to notice that water plants have an advantage over land plants in connection with the amount of carbon dioxide readily available to them. Carbon dioxide is soluble in water, and is usually present in greater proportion than it is in air. They are not so fortunate with regard to light because some of the intensity of the light and also the rays are lost in their passage through the water.

Exp. Set up three pieces of apparatus as in Fig. 442, each containing the same quantity of plant. Place one under a double-walled bell-jar with a blue coloured solution, such as copper sulphate, between the walls; the second under a bell-jar containing orange coloured solution, and the third, leave in daylight or white light. It will be found that most oxygen is formed under the influence of white light, a good deal under that of orange, and least under that of blue. White light consists of the seven colours of the rainbow, or the spectrum, which occur in the order:

red, orange, yellow, green, blue, indigo, and violet, so that the orange is near one end while blue is near the other. The plant makes special use of the orange part of the spectrum when giving out oxygen.

The inter-relationship of plants and animals living in water in connection with oxygen and carbon dioxide can easily be appreciated.

STARCH FORMATION. Gather some green leaves of any plant after a period of sunshine. If the protoplasm of the leaf be killed by boiling in water for a few minutes, the green colour can easily be extracted by pouring off the water, and covering the leaf with alcohol or methylated spirit. The leaf will have become rather stiff and brittle, but can be softened again by placing in water for a few minutes. If now iodine solution be applied, a dark blue colour will be seen, indicating the presence of starch.

Some leaves, such as iris, do not make starch, but all leaves make sugar to some extent. If some iris leaves be taken and crushed in a mortar with a small quantity of water, a solution containing the soluble materials will be obtained. On treating this solution with Fehling's solution a red precipitate will indicate the presence of a reducing sugar.

The first essential for starch formation is that the plant be green. Only those parts which contain **chlorophyll** can manufacture starch. Toadstools and mushrooms do not contain starch.

EXP. Take a variegated leaf, *e.g.* a geranium, after a period of sunshine, make a plan of the leaf showing the green parts, decolorise, and test for starch as above. Starch will only be found in those parts which were green.

The second essential condition is **light**. If a plant be placed in the dark for about twenty-four hours the leaves will contain no starch.

Exp. Cover a portion of a leaf, top and bottom, with tin-foil or dark paper (Fig. 443). Then subject the leaves to the influence of sunlight for a few hours. Remove the covering materials, decolorise, and add iodine. Blue colour will be produced in those parts of the leaf which were receiving light, not in the covered parts.

The third necessity is **carbon dioxide** in the atmosphere or, in the case of a water plant, in the water.

Exp. Place a growing plant in a pot under a bell-jar together with a small dish containing caustic potash, and leave in the sunshine. Later decolorise and test for starch. It will be found that there is none. The caustic potash has absorbed the carbon dioxide from the air beneath the bell-jar, and this has prevented starch formation. In this case a leaf from a similar plant left in the ordinary air, or preferably placed beneath a bell-jar with no caustic potash, should be used as a control.

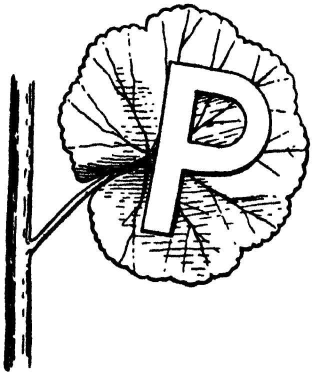


Fig. 443. Geranium Leaf. Attached to growing plant with portion P covered to exclude the light.

If a suitable leaf be available, it can be arranged so that part of it is in an atmosphere from which the carbon dioxide has been absorbed by caustic potash, and the remainder is in the air outside (Fig. 444). This is known as Moll's Experiment because Moll first performed it. When decolorised and tested, only the part of the leaf outside the bottle shows the presence of starch.

The preceding experiment can be modified by placing one whole leaf in the enclosed space and using another whole leaf from the same plant, which can be left growing in a pot, or a branch of leaves can be used.

These experiments all show that only when a sufficient supply of carbon dioxide is available can starch be formed. No starch is formed if it is too cold. Leaves collected on the cold days of winter show no starch. Similarly if kept cool with ice, no starch will be formed. If the leaves are covered with vaseline, so that the pores of the stomata are blocked, no starch formation will occur.

The above process is a very fundamental one in connection with life. It is known as **photosynthesis,** which is a building-up by means of light energy. In this process carbon dioxide and water are built up into carbohydrates, with the liberation of oxygen. Chlorophyll absorbs the light energy.

This formation of carbohydrate material is the foundation stone on which all plant and animal food is built. From carbon dioxide and water, formaldehyde, CH_2O, is produced. Six molecules of formaldehyde make glucose, $C_6H_{12}O_6$. From glucose starch $(C_6H_{10}O_5)n$, is made and deposited as solid, visible grains in the cells.

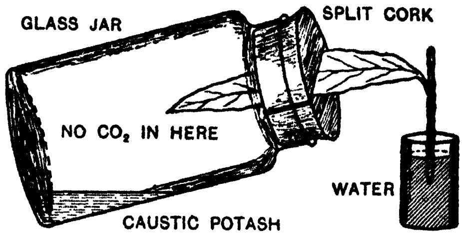


Fig. 444. Moll's Experiment.
To show that carbon dioxide is necessary for starch formation.

Other forms of reducing sugar than glucose may be produced, and some plants form saccharose or cane sugar, $C_{12}H_{22}O_{11}$. This is obtained from two molecules of glucose minus one of water.

By the gradual building up of more and more complex molecules in the way indicated, energy is stored in the plant. It is this energy which has been stored in the past in coal, making it now a valuable source of energy which can be unlocked and used.

The formaldehyde and glucose may be used as respiratory material to supply immediate energy. (See Chapter XXVII.) Further synthesis may occur, forming proteins or even protoplasm itself. The carbohydrate material may be translocated and stored or used elsewhere.

For translocation the starch must be again rendered soluble. This is done by the action of the enzyme diastase, which converts it into sugar, as described in Chapter XXIII. This work goes on during the hours of darkness, so that the leaf cells, which may be regarded as a factory, may have their goods removed, and thus be ready to start afresh next morning. This leaf factory needs as its raw material carbon dioxide and water, with which it manufactures sugar. The waste product of the manufacture is oxygen.

2. FOOD FROM SOIL

In Chapter XXIII. we saw that plant ash contains certain mineral salts which are present also in the soil from which the plant has taken them by osmosis. The necessity for certain chemical elements to a plant and the part they play in its life can be shown by means of water culture experiments.

Plants can be grown with their roots dipping into food solution, and thus their food can be controlled and known with accuracy. It has been found that ten elements are generally necessary for ordinary plants: carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, magnesium, iron, and calcium. The carbon, as we have seen, is obtained from the air, and we have also shown that no plant will live without hydrogen and oxygen, which it obtains from water. The remaining seven are present in soil as soluble mineral or inorganic salts.

If a solution is made containing all seven, it is called a **normal culture solution**, because it contains all the food materials a plant should normally want for its cultivation.

This solution must be very dilute and made with pure salts. A normal culture solution which gives good results is:—

1 grm. Potassium nitrate.
0.5 " Calcium phosphate.
0.5 " Calcium sulphate.
0.5 " Magnesium sulphate.
A few drops of Ferric chloride.
100 c.cm. Distilled water.

This solution must be diluted for use, so that one part is used in ten parts of distilled water.

Preparation for Experiments.—A series of solutions should be made omitting one element at a time. It must be noticed that each salt involves two elements, for instance, potassium nitrate supplies potassium and nitrogen. The second must be added in some other form. Care must also be taken to keep the concentration of the solutions the same, the pH value being of the utmost importance in connection with the utilisation of the substances in the solution.

To make a complete series eight are needed: the normal solution, one omitting nitrogen, one omitting sulphur, one without phosphorus, one without potassium, one without iron, one without magnesium, and one with no calcium.

In starting the experiment every possible care must be taken that the jars used are absolutely clean. They should be equal in size and must either be opaque or covered with black paper. This provides the darkness in which roots normally grow, and it also prevents the growth of any small green forms of plant life, which may have got in unnoticed as spores or microscopic organisms.

Seedlings or cuttings can be used, but very great care must be taken that the roots are quite clean and free from any substances which might play a part as food material. It is a good plan to raise them in clean sand, because this easily washes off, without causing damage to the roots.

A convenient cork is shown in Fig. 445. The plant can easily be placed in the larger central hole without damage.

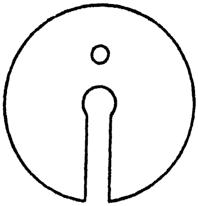


Fig. 445.

The plant should be protected at this part by a small pad of cotton wool, which must always be kept dry. The axis of the plant must also have room to expand and grow at this region. It must be held, but only very loosely. As growth takes place it will probably be found that a little support is needed by the stem, as the root cannot hold firmly in the water as it would in soil (Fig. 446). A hollow glass rod placed through the second hole serves very well to tie the stem to, and it allows a little air to pass down to the solution beneath. Through it air can be pumped occasionally.

When all are prepared they should be placed in as nearly the same position as possible, care being taken that one does not shield the other from the light. It is important that the plants are as nearly alike as possible at the beginning of the experiment, so that any inequalities may be detected. Distilled water must be added as often as needed to make up that lost by absorption and subsequent transpiration. Once a month the jars should be well rinsed out and new solution supplied.

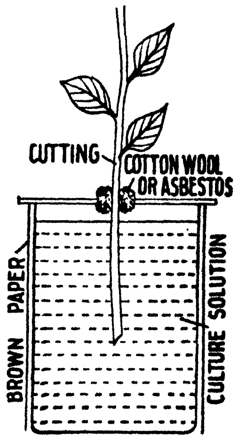


Fig. 446.
WATER CULTURE EXPERIMENT.

Cuttings of Fuschia and Tradescantia, seedlings of Sycamore and Nasturtium (*Tropaeolum*) give good results. The differences between them will become more marked as the weeks go on. The seedlings will show differences more quickly if the cotyledons be carefully

removed, so that their reserve food has gone and they therefore have to utilise what is given to them. Water plants can be used. *Lemna* (Duckweed) responds well. It is important to start with the same number in this case. If water plants are used, the top of each jar, which will not be filled, must be covered with a glass plate to keep out dust. Land plants may be grown in pots of sand, which has been washed thoroughly clean, and watered with the respective culture solutions.

THE BUILDING-UP OF LIVING MATERIAL.—After about a fortnight it will be seen that some of the plants are growing better than others. Fig. 447 shows a series of Tradescantia cuttings which have been grown for several weeks in culture solutions. Six elements actually enter the composition of the living protoplasm. These are carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. The carbon is obtained from the carbon dioxide of the atmosphere and the hydrogen and oxygen from water, in all cases.

The culture solution from which the nitrate was omitted very soon shows signs of stunted growth in the aerial part. The stem is short and the leaves are small, each one getting smaller than the preceding. The root, however, is long and thin, having apparently grown as far as possible in search of the missing food. This plant after a time will be unable to struggle on, and will die.

The nitrate probably joins in the leaf with newly-formed formaldehyde to make formhydroxaminic acid, which condenses with more formaldehyde to produce amino-acids and nitrogen bases. These amino-acids have acid COOH and alkaline NH_2 groups, which enable one molecule to easily condense with another. Such linkage forms proteins, which are colloidal complexes of very low electrical conductivity such as are present in plants. These proteins are suspended in a medium with a definite pH, which is usually between 4.0 and 5.5.

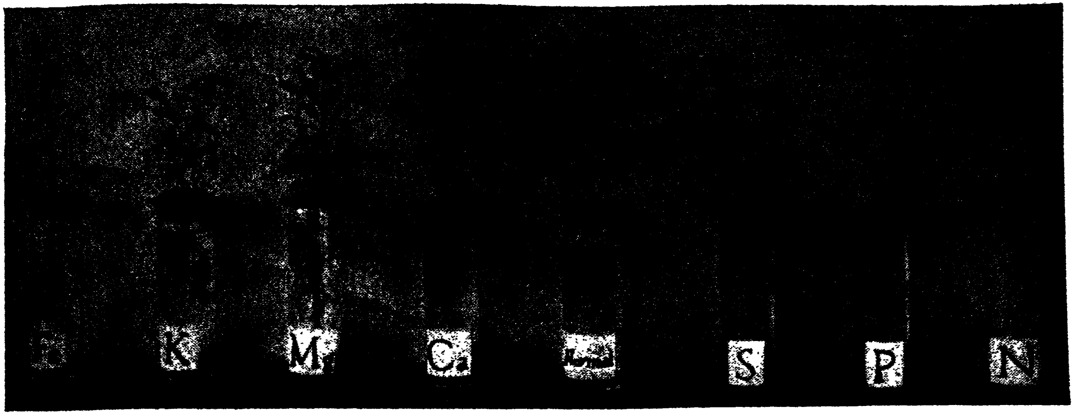


Fig. 447. WATER CULTURE EXPERIMENT.

Fe indicates the absence of iron.	K indicates the absence of potassium.
Mg ,, ,, ,, ,, magnesium.	Ca ,, ,, ,, ,, calcium.
S ,, ,, ,, ,, sulphur.	P ,, ,, ,, ,, phosphorus.

N indicates the absence of nitrogen.

Another element, the absence of which soon becomes evident, is iron. Iron does not enter into the composition of protoplasm or of the green colour chlorophyll, but without it the machinery of chlorophyll formation does not work; the foliage very soon shows signs of lack of chlorophyll, and gradually the new leaves become smaller and white. This plant is often the smallest, because without chlorophyll, photosynthesis cannot go on, therefore the entire work of food-building is stopped at its source.

The absence of the other elements does not show so quickly, and varies a good deal with the plant used. Potassium plays some part in connection with the formation of carbohydrates, and lack of it produces a somewhat stunted growth after a time.

Magnesium enters into the formation of chlorophyll and plays an active part at the growing points of stems and roots. Without this element cuttings grow roots very slowly.

Sulphur and phosphorus enter into protein molecules. In the absence of sulphur the internodes are usually shortened to some extent and very often a reddish or yellow tint occurs in the foliage. Phosphorus in some cases makes a marked difference, because when it is not present an interference with the translocation of food arises. It is thus evident that phosphorus plays a part in connection with the enzyme action needed to convert starch and fat into suitable soluble forms.

In the absence of calcium, plants more easily become diseased. They are also liable to develop discoloured foliage. When salts are dissolved in water they undergo what is called dissociation, that is, they separate into two parts, *e.g.* potassium nitrate separates into potassium ions, as they are called, and nitrate ions, each carrying a minute electric charge. The potassium ion carries a positive charge, and the nitrate ion a negative charge. It is the ions which are absorbed by the plant. Calcium plays a

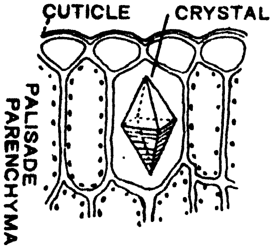


Fig. 448. Leaf.
Part of transverse section (region of the upper surface), showing a crystal in one of the cells.

useful part in combining with the negative ions, and this reduces the acidic properties of the cell-sap and increases the pH value. This is important because, in order that the protoplasm may be kept in good condition with efficient power of absorption and ability to allow solutions to pass through it, the cell sap must be nearly neutral, or the pH value very nearly 7.

This important work of calcium is often seen in sections where we find in the cells crystals of calcium oxalate, which have been formed by the calcium combining with oxalic acid formed as a by-product of metabolism. The perfect form of these crystals is shown in Fig. 448, and they sometimes occur singly in cells in this way. Often a group of them occurs in one cell and in this case they either form a cluster (Fig. 449, B) or a bundle of long, slender needles (Fig. 449, A). The clusters, known as sphaeraphides, are common in the cortex of stems as well as in leaves. When they occur in the needle form, known as raphides, they have another valuable use. They may be found in the basal part of the leaves of Daffodils and Hyacinths, and it is well known that these do not usually fall a prey to snails. This is because the crystals are sharp and hurtful to them on account of the formation of their "tongue and teeth."

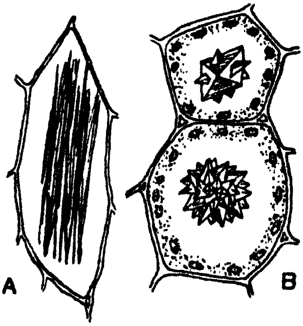
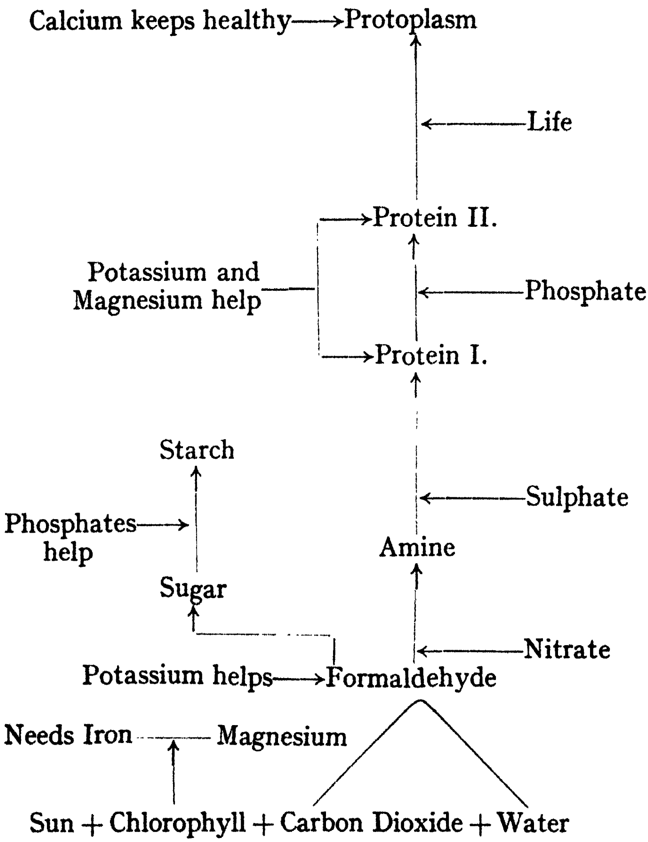


Fig. 449. Cell.
A, with Raphides; B, with Sphaeraphides.

The following table helps to show the relationship between the ten essential elements and protoplasm.



It will be seen that some elements take part in the composition of essential parts of the plant, while others help the mechanisms to work. Besides those universally present, some plants have a special use for others, *e.g.* grasses use silicon to make their stems strong.

Plants of the Pea and Bean type also seem to have a special use for boron, and there may be many other substances which play a large part in some plants.

There may be many other conditions needed for the formation and functioning of different parts of the plant mechanism. Thus chlorophyll cannot be formed continually in the absence of light. Seeds can be germinated and grown in the dark, but the aerial part is not green, nor is its form the same as if grown in the sunlight. This type of growth has been utilised in connection with food plants, and everyone is familiar with the effects of the absence of light, known as **etiolation**, in Asparagus and Celery. The yellowish colour is due to a substance called etiolin which readily becomes changed to chlorophyll as soon as it gets access to light. Elongation of stems and petioles with diminution of leaves is a characteristic accompaniment. The food contents are also rather different because there has been no photosynthesis in these parts. They are also succulent and crisp because transpiration has been reduced by the same conditions. The cotyledons of a few seeds, *e.g.* Sycamore, contain chlorophyll although they have developed inside the testa and pericarp. This, however, is the embryo plant's initial supply provided by the activity of the parent tree, the seedling has no power of adding to it in the absence of light. Less light is needed for chlorophyll formation than photosynthesis.

It has been found that in addition to the actual food substances needed by the plant, there are certain others, which Bottomley called **auximones**, which are essential for the effective utilisation of these food substances. These are growth-promoting substances and they are comparable in many ways with the vitamins associated with animal life. (Chapter XXVI.) They are products of bacterial decomposition in the soil, and may be one of the reasons why plants must have a supply of " humus " continually

present in the soil, in addition to the actual mineral salts, if they are to remain healthy. It must also be remembered that all animals ultimately depend on plants for their food, and consequently it is vital to them that the plants should be healthy and strong and contain all those constituents which they need for their well-being and perfect development.

Plants which, like the normal green plant, are able to use inorganic molecules from which to derive all the food materials they need are said to be **autotrophic.** Some plants, *e.g.* parasites, and all animals need to be supplied with organic materials; these are called **heterotrophic.** The term **prototropic** is used for a few bacteria, *e.g.* the nitrogen-fixing bacteria (see Chapter XXX.), which are able to utilise substances in the form of elements.

CHAPTER XXVI

THE FOOD OF ANIMALS

1. INTRODUCTORY

Animals are either vegetarians, feed on other animals, or indulge in a mixed diet of plant and animal food. The constituents of plants have been found to be water, carbohydrates, proteins, oils, and mineral salts. Since animals feed on plants and their bodies consist of the same essential material, namely protoplasm, it is reasonable to expect their bodies to consist of the same constituents. Flesh can be shown by Millon's reagent, or the Xanthoproteic test, to consist of protein. Animal bodies contain a good deal of sugar, and in the liver there is a quantity of a form of starch known as animal starch, or glycogen. Very often, instead of the oils of a plant, we find in an animal fat. This has essentially the same composition, but is more solid in form. Mineral salts are also present in an animal. Thus we see that whatever may be the outward form of an animal's diet, it consists essentially of the same constituents.

2. VITAMINS

In addition to substances with actual food value, there are certain others which are fundamentally necessary to animals in order that they may adequately utilise the food substances. These are known as **Vitamins**, and they correspond to the auximones of plant life. (Chapter XXV.) Only a very small proportion of these substances is needed, but in their absence, deficiency in the animal's nutrition very soon affects its growth, and lowers its resistance to disease. Vitamins are complex organic substances, at present known as Vitamins A, B, C, D, and E.

Their action is thought to be in a large measure catalytic. Their activity is impaired by heat. They are present in the quite fresh natural food of the young animal.

VITAMIN A.—Vitamin A, the first to be named, is spoken of as being fat-soluble, because it can be dissolved by such solvents as ether and alcohol, which dissolve the fats with which it is associated. A very valuable source of vitamin A to the human race is cod liver oil. This the fish obtained from smaller fish, and these ultimately from the lower forms of animals and seaweeds. It is also present in milk and butter, which have a much richer supply in summer, when the cows feed in pastures, than during the winter months, when they are fed artificially. Carrots and green leafy vegetables are also a good source of this vitamin. In its absence the general growth of rats, dogs, rabbits, poultry, and children is considerably impaired. Its absence also causes disorders of the eyes.

VITAMIN B.—This was the first to be discovered. It is soluble in water and therefore spoken of as water-soluble vitamin B. During the process of polishing rice this substance is somehow removed, with the result that when man is fed too exclusively on polished rice he develops a disease known as beri-beri, and also nervous disorders; fowls so fed develop polyneuritis. It is very widely distributed in the embryos of edible seeds, and is present also in the coverings of the cereal grain. It is stored in the liver and kidneys of animals. When it is deficient the harmony in the proportions of mineral substances in the body seems to be disturbed.

It is now thought probable that there are two substances included in the term vitamin B, the second one being active in preventing dermatitis. Yeast is a very efficient source of the dual vitamin B. It is interesting that this is a unicellular plant, in which therefore the entire work, feeding and reproduction, is comprised within the one cell.

It is thought possible that bacterial activity within the intestine may play a part in producing this vitamin in the animal when conditions of food and living are favourable.

VITAMIN C.—This is also water-soluble, and is present in Lemons, Oranges, Tomatoes, Cabbage, Lettuce, Spinach, French Beans, Peas, and Turnips. Deficiency or absence of this vitamin has played a great part in wars and also in life in the navy. The disease known as scurvy usually appears when fresh foods of the above nature are unavailable.

VITAMIN D.—For some time the above three vitamins alone were known; but vitamin D has now been separated from the old vitamin A, as the special part which is concerned with the proper development of the bones of the body. In its absence these do not become hard and strong, and rickets develops; thus showing that the utilisation of calcium and phosphorus has been impaired. This is a very uncommon disease amongst Icelanders, Eskimos, and Lapps, because of the large quantities of fats rich in vitamin D which enter into their diet. Sunlight, particularly the ultra-violet rays, are looked upon as a somewhat effective substitute for vitamin D. Fresh, green leafy vegetables, like Spinach and Lettuce, rich in vitamin A, if gathered and exposed to ultra-violet rays, are believed to become rich in vitamin D. Similar exposure has this same beneficial effect on milk.

VITAMIN E.—Some experiments in which rats were given a synthetic diet, have led to the idea of another substance, called vitamin E, which plays an important part in connection with reproduction. The rats so fed had no litters. This vitamin is fat-soluble, and is abundant in the embryo of the wheat grain.

As work in this direction develops the need for all young creatures to be fed on a natural diet under as natural circumstances as possible becomes more and more apparent.

The provision of food substances is important, but not of much avail unless the ability to use them is also supplied. However many or few vitamins may later be isolated and described, something else in addition to carbohydrates, fats, proteins, and mineral salts, seems quite necessary before an animal grows normally, keeps healthy, and reproduces its kind. It is also interesting that the ultimate source of the vitamins is to be found in plant life.

3. DIGESTION

Before any of the food substances in the diet are of any use to the animal they must be rendered soluble by the process of **digestion.** Each substance has to be acted on somewhat differently, and a number of enzymes exist, each of which attacks a different part of the diet. As it passes through the digestive tract the solid and complex food is gradually unravelled and changed in form by these enzymes, which, present in comparatively small quantities themselves, change large quantities of material and remain unchanged themselves, like catalysts in chemical reactions.

STARCH.—This is insoluble and therefore it is changed into glucose. In the mammals, many of which take a good deal of vegetable food and therefore rather a lot of starch, there are special **salivary glands** leading into the mouth. Digestion in these animals starts here, where the food is broken into smaller pieces by the teeth and subjected to the action of the saliva. The saliva contains an enzyme called **ptyalin,** which converts the starch into glucose, thus fulfilling the rôle of diastase in plants, but not being called upon to bring about the reverse reaction, namely conversion of glucose to starch. When the glucose reaches the liver, an enzyme present there converts the greater part of it into a form of starch known as animal starch, or **glycogen.** This is stored in the liver until needed. when the enzyme causes the reverse action, namely its

conversion back into glucose again. In this way glucose is given to the body in small quantities as required.

We possess salivary glands and saliva, the action of which can be demonstrated as follows:—

EXP. Prepare a 1 per cent. starch paste. To make this stir the starch with a little of the water cold, boil the remainder of the water, and add this to the starch and cold water, while stirring. Put the starch paste into two test-tubes and into one introduce a little saliva. At intervals of about three minutes put into each a drop of iodine. The one containing the saliva will ultimately, probably after about nine minutes, show no sign of the blue colour with the iodine, showing that starch is no longer present. When this is the case boil a little of it with Fehling's solution, when an orange precipitate will denote the presence of glucose. A little further time may be necessary to show that the starch has actually become glucose.

The starch which remains undigested by the saliva is further acted upon in the small intestine by an enzyme **amylopsin.** This is secreted by the pancreas and enters the intestine along the pancreatic duct. Saliva is of course swallowed, but its action is stopped soon after it enters the stomach because the gastric juice is acid.

SUGARS.—**Glucose** is already soluble and therefore needs no converting. An animal's diet may contain other forms of sugar, notably the cane sugar, **sucrose,** of plants, **lactose,** or milk sugar, and **maltose,** also present in plants. These three are non-reducing sugars, that is, give no precipitate with Fehling's solution until they have been boiled with acid, *e.g.* hydrochloric acid. They are each converted by their own specific enzyme into glucose. The three enzymes, namely **invertase, lactase,** and **maltase,** are present in the digestive juice, called succus entericus, secreted by glands in the wall of the small intestine.

PROTEINS.—These are subjected to the action of the gastric juice in the stomach. This contains an enzyme, called **pepsin.** As pepsin can only act in the presence of acid, the glands of the stomach have two kinds of cells, central cells which secrete the pepsin, and oxyntic cells which secrete hydrochloric acid (Fig. 198, Chapter XII.). Pepsin converts the proteins into peptones.

EXP. Pepsin can be obtained as a white powder. Make a solution of it and put this into two test-tubes. To one add a little dilute hydrochloric acid and into both put a small piece of solid white of egg. After a few hours the egg in the one containing the acid becomes dissolved.

When the proteins pass from the stomach to the intestine they are acted upon further by another enzyme, **trypsin,** which is poured into the intestine from the pancreas. This converts the proteins into amino-acids and can only work in the presence of alkali, namely sodium carbonate in the pancreatic juice. Further, the actual substance produced by the pancreas has to be converted into trypsin itself by an activator present in the succus entericus. The bile which enters the intestine from the liver is alkaline. Those proteins which become peptones in the stomach are converted by erepsin in the succus entericus into amino-acids.

FATS AND OILS.—No attack is made upon these until they arrive in the small intestine, and here they are acted upon by a third enzyme from the pancreas. This enzyme is one of a group denoted by the name **lipase.** In order that this may do its work the fats and oils must be emulsified. The fats become melted by the high temperature in the stomach and emulsification is brought about partly by the alkalinity of the pancreatic juice, and partly by the action of the bile. Lipase splits up the fats into **glycerol** and a **fatty acid.** This work is completed by another enzyme of the lipase group present in the succus entericus of the small intestine.

The walls of the alimentary canal, throughout its length, are muscular and therefore capable of contracting and expanding. The movement is called peristalsis and it forces the food down the oesophagus into the stomach, and also slowly along from loop to loop of the intestine. The muscular action of the stomach wall causes a churning of the food, and this aids its digestion.

4. ABSORPTION

Having thus become digested the food must be **absorbed** into the body. As it is now in a soluble form it can pass by **osmosis** (Chapter XXII.) through the epithelial cells of the alimentary canal. All the digested food, except that formed from the fats, enters into capillary blood vessels, so that it can be conveyed in the blood stream to various parts of the body. A certain amount of water and any iodides present pass through the wall of the stomach, but the remaining substances do not leave the food tract until they have reached the small intestine. In the villi (Fig. 450) of this there are tiny lacteal vessels, as well as blood capillaries, and the digested fats pass into these, while sugar, amino acids, and mineral salts pass into the capillaries. Having reached the lacteals, the fats are converted back into their original form so that the lymph, that is the fluid in the lacteals, is an emulsion of fats and oils and is milky in appearance.

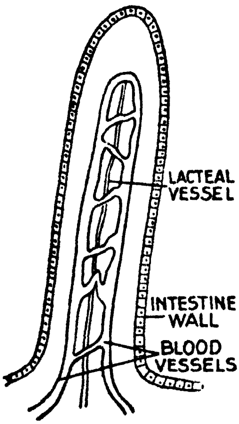


Fig. 450. Part of Inner Wall of Intestine.

Only undigested food and water enter the large intestine, and most of the water passes out of it by osmosis, so that almost solid waste material remains to pass out of the

large intestine. Osmosis through animal tissues can be demonstrated by obtaining from a butcher the bladder of a pig or bullock, preferably the latter as it is stronger.

EXP. Soak a piece of the bladder in water for some hours, then tie it very tightly with cotton over the wide end of a thistle funnel. It must be so tight that a solution poured into the funnel will not leak out. Into the funnel pour a strong solution, either of sugar, protein, or a mineral salt, so that it reaches a short distance up the tube. Stand it in a beaker containing water, or a very dilute solution of the same substance as that inside the funnel. Mark the level of the solution in the funnel (Fig. 398). After about fifteen minutes the liquid will be seen to rise in the funnel and, if a length of glass tubing is attached by rubber tubing to the funnel, it will reach a height of several feet.

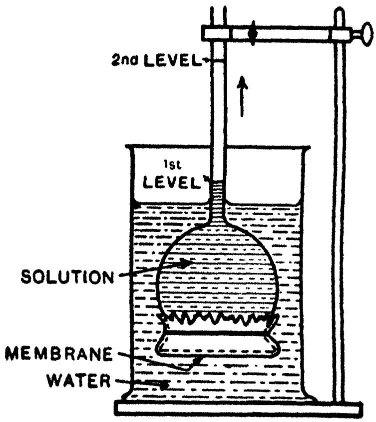


Fig. 451. EXPERIMENT TO SHOW OSMOSIS.

5. ASSIMILATION AND DISINTEGRATION

Having been absorbed into the blood, the food has next to be **assimilated,** that is, built up again into a particular form of protein that is suitable to enter into the constitution of the protoplasm of the body. Carbohydrates and fats act as fuel; they are consumed in order to give the body the energy that it needs. There is a little carbohydrate fuel, namely glycogen, stored in the liver, but the main store of fuel laid up in the body is in the form of fat, which occurs in all sorts of places. Before an animal

hibernates a large supply of fat accumulates in the body, and this fuel is drawn upon during the winter sleep.

Proteins are not fuel, but body builders, since they become part of the protoplasm itself.

During digestion, useless and even harmful, substances are produced and these form waste products to be excreted. When proteins are digested a large quantity of ammonia is formed and passes into the blood. This is harmful to the body and must therefore be got rid of. As already seen all the blood from the intestines reaches the **liver,** by way of the hepatic portal system, and in the liver ammonia is converted into urea. As the blood passes through the kidneys they extract the urea and any substance that is present in too great quantity, *e.g.* salt. The substances extracted by the kidneys dissolved in water form urine, which collects in the bladder and is expelled from the body.

Conversion of ammonia to urea is only one part of the work done by the liver. It also renders harmless, substances formed by bacteria in the intestine and can consume bacteria themselves. The bile is produced by the liver, so from that point of view it is a digestive gland. It is also a storehouse, for when the quantity of sugar entering it is in excess of what is required, the liver converts it into glycogen and keeps it in that form until needed.

In any animal that is to survive there must be assimilation of food. Some of the new material is used to build up tissues, but a good deal is broken down or disintegrated into simpler substances. In this disintegration of complex molecules energy is freed and this enables the animal to carry out its life processes. These two processes of assimilation and disintegration are together known as **metabolism.** The building-up process of assimilation is **anabolism,** and the breaking-down process **katabolism.**

CHAPTER XXVII

RESPIRATION

Every living organism, plant and animal, must breathe to obtain the energy needed to carry out its life processes. Every living cell must breathe both during the day and during the night: whether it be in the light or in the dark, whether it be green or any other colour, while there is life, breathing, or respiration, goes on continually.

In respiration, oxygen is taken from the air and carbon dioxide and water are liberated, together with energy, some of which appears as heat.

Exp. Set up the experiment shown in Fig. 452. If this apparatus be not available, inverted flasks, fitted with one-holed rubber corks through which passes a piece of glass tubing, may be substituted. Germinating seeds or flowers can be used. The small test-tube in **A** contains caustic potash to absorb the carbon dioxide as it is produced. Coloured water in **C** shows clearly. The stop-cocks **D** should be opened at the commencement of the experiment, so that the levels of the coloured water in the tubes will be the same as the levels outside. This position in the graduated tube should be noted; and the stop-cocks then closed.

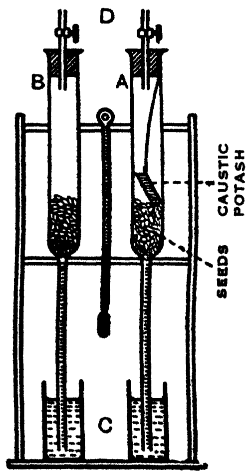


Fig. 452. To show respiration of seeds.

After a time it will be found that the coloured water has risen in the tube of **A**, showing a decreased volume, because the plant has been taking in oxygen and giving out carbon dioxide in its place; but the

carbon dioxide has disappeared into the caustic potash, so that the volume has been reduced; the amount of reduction can be read off on the tube. In **B** the volume remains the same, the coloured water remains at the same level, showing that the volume of the oxygen taken in is equal to that of the carbon dioxide given out. Slight variation will occur owing to temperature changes. It is important, therefore, that readings should be taken when the temperatures are as nearly as possible the same.

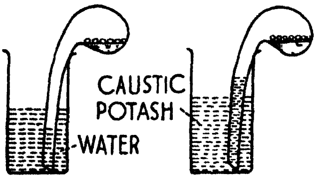


Fig. 453.

Satisfactory results are also obtained by using respirometers as shown in Fig. 453. Seeds and damp cotton wool should be placed in the large part and one inverted in water, the other in caustic potash. If measuring cylinders be used the difference in volume can be read off directly.

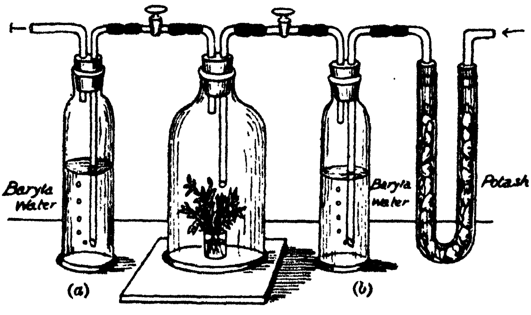


Fig. 454. The arrows show the direction of the current of air, which is drawn through by attaching an " Aspirator " at the left of the apparatus.

The apparatus shown in Fig. 454 is a very useful one for experiments on respiration. Air is drawn through the whole apparatus by means of an aspirator. The rim of the bell-jar must be well greased to make an airtight connection

on the plate. A flask with a little moisture in it could be used in place of the bell-jar. It is important to notice that the tube on the side where the air is coming in is the one which dips right into the liquid, while the other does not.

The air on entering the apparatus is freed from carbon dioxide by passing through caustic potash. That no carbon dioxide is now present is shown by the Baryta water in (*b*) remaining clear. If the bell-jar be left empty the Baryta water in (*a*) will also keep clear. If some plant material be placed in the bell-jar then the Baryta water in (*a*) will very soon become cloudy, showing that the carbon dioxide free air which arrived at the bell-jar has, from there, received a supply of carbon dioxide, which must have been produced by the living plant material. Lime water could be used in *a* and *b*.

If green leaves be used in the light no change will occur in (*a*), but if a dark cloth be put over the bell-jar so that the green leaves are in the dark, then the Baryta water in (*a*) begins to get cloudy.

This apparatus can be used to give relative ratios of respiration. The same weight of plant material should be used, and the air allowed to pass over for the same period of time; (*a*) must be weighed at the beginning and end of the experiment. The difference in weight is mainly due to the carbon dioxide absorbed which has been breathed out by the plant material.

A much simpler form of the apparatus just described is shown in Fig. 455. Two should be set up, one containing germinating seeds, and one in which they are omitted, acting as a control. The two clips render the flask air-tight. After a few days the clips should be released, when the water will run from the funnel into the flask and force air from it to bubble into the test-tube of lime water. In the apparatus containing seeds, the lime water will turn milky, but in the control it remains clear, thus proving that the germinating seeds have produced carbon dioxide.

While producing carbon dioxide, any living organism is consuming oxygen.

EXP. Take a series of gas jars and into each put a small test-tube containing lime water and some damp blotting-paper. Into one jar put nothing more, into another germinating seeds, into others a twig with opening buds, flowers, green leaves, fruit, underground parts, *e.g.* bulb, potato. Put a greased glass plate on to each one. Stand in a warm, sunny place, and leave for twenty-four hours or so. It will be noticed that practically no change has taken place in the first jar, but in all the others, except that with green leaves, the lime-water has become cloudy, showing the presence of carbon dioxide. If the plate be removed and a lighted splint inserted it will be found to be extinguished almost immediately in those in which lime-water has gone cloudy, showing that oxygen, the supporter of combustion, has been removed from the air in these cases.

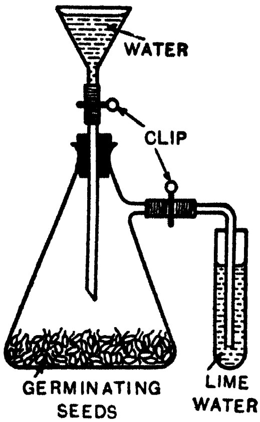


Fig. 455. Respiration Experiment, showing Production of Carbon Dioxide.

The preceding experiment should be repeated, placing the jars in the dark. It will then be found that in every case containing plant material the lime-water is cloudy and the splint quickly extinguished.

These experiments, except the one on green leaves in light, show that all parts breathe in light and darkness. Actually green leaves in sunlight are breathing too, but they are also carrying on another process, photosynthesis, described in Chapter XXV., which hides the effects of respiration.

When a piece of coal, wood, or other substance is burned, the complex substances, which were built up by photosynthesis and other endothermic processes in the living plants, are broken down by the action of the oxygen of the air. As a result carbon dioxide and water are formed, and the energy stored in the coal, etc., is unlocked and appears as heat. This energy so unlocked can be used to do a variety of work, for instance, drive a train, a mill, a motor, and so on. Respiration is the same kind of process, only it goes on very much more slowly. The oxygen taken in causes a very slow combustion of materials, particularly carbohydrates, in the plant. As a result carbon dioxide and water are formed, and the energy which was locked up in the carbohydrate is liberated. Respiration and combustion are both exothermic processes, in both some energy becomes apparent as heat.

Exp. Take two thermos flasks fitted with one-holed corks, through which pass thermometers. Germinating seeds give good results and can be put into the flasks easily. If about fifty pea seeds be boiled to kill them, then cooled and placed in one flask, and fifty germinating peas be placed in the other, and the thermometers carefully read, they should give the same temperature. If they are again read the following day there will be a difference of about 2° C., the one containing germinating seeds being 2° C. higher than the other. This extra heat must have been given out by the living seeds.

When a plant is in difficulty, it often has the power of, in part, overcoming it. This may be shown, with regard to respiration, as follows:—

Exp. Fill two test-tubes with mercury and invert each into a dish of mercury. Clamp them upright, leaving a space between them and the bottom of the jar. Insert into the open end of one test-tube, four soaked pea seeds from

which the testas have been peeled, and into the other, four which have been killed by boiling and peeled. As the seeds are much lighter than the mercury they will rise to the top of the tubes, but can be scarcely seen because of the mercury. At the end of a day or so, the live peas will have become visible, as there will be a space at the top of the tube (Fig. 456), but there is no change in the other apparatus.

Evidently the live peas have given out a gas, which may be tested by inserting a lump of wet caustic potash or caustic soda. The mercury will gradually rise to the top of the tube again as the caustic soda absorbs the gas, which is therefore carbon dioxide.

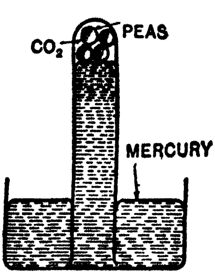


Fig. 456.
INTRAMOLECULAR RESPIRATION OF GERMINATING PEAS.

From the above we see that the seeds have respired although they have no oxygen. The molecules of the carbohydrate substances in their cotyledons have become split up into simpler substances, including water and carbon dioxide, in order that the seeds might have energy. This is called **intramolecular respiration.** It may serve to tide over an adverse period, but it is an expensive process. The decomposition is incomplete and consequently alcohol is usually formed as in the metabolism of yeast (Chapter XXIX.), and this has an inhibitory effect upon the activity of the protoplasm.

It is the energy liberated by respiration which is used by the plant to do everything it does, and which results in growth. Those parts which are doing most, such as germinating seeds, opening buds in the spring time, places where changes take place rapidly, respire much more freely than fully formed parts, where only a steady supply of energy needs to be maintained to keep the life processes going on.

Where there is active growth new cells are being made, and more and more cells need a supply of energy. Again animals use a lot of energy in locomotion and muscular movements, consequently respiration must go on quickly.

Everyone is familiar with breathing in and breathing out, or inspiration and expiration, in animal and human life. When you breathe in your lungs are filled with air, and when you breathe out air is expelled from them. In order to force the air out, the cavity of the thorax must be made smaller, and this is brought about by two things acting in unison. The diaphragm arches forwards and the ribs are pulled back by the muscles between them. The air sacs in the lungs readily become smaller as their walls are elastic. This can easily be shown in dissecting a rabbit. If a hole is pricked in one side of the diaphragm, air at once rushes into the pleural cavity on that side and the lung quickly collapses, while that on the other side remains distended unless the diaphragm be pricked to admit air into the other pleural cavity. Expiration is almost immediately followed by inspiration, in which the diaphragm becomes flattened and the ribs pulled forward by another set of muscles. This would tend to leave a vacuum inside the enlarged thoracic cavity, thereby causing diminished pressure on the outer surfaces of the lungs, but the air rushes in through the nostrils to fill this vacuum, and the air sacs become distended by it so that the lungs expand.

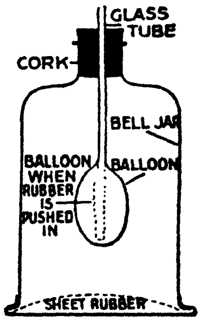


Fig. 457.

Inspiration and expiration can be illustrated by a very simple piece of apparatus shown in Fig. 456. The rubber sheet over the mouth of the bell-jar can be pushed in with the fist, causing the balloon to collapse, and on removing the fist the balloon will expand again.

We now need to discover what changes occur in the air which we breathe in, that is, how it differs from ordinary air, and to do this we must perform some experiments.

Exp. Take a flask or other vessel of cold water and breathe on it. It will become misty and will feel damp. Those who know sufficient chemistry will be able to test this dampness with white copper sulphate, and since this substance turns blue, tell us that it certainly is water. Our breath does not contain actual drops of water; if this were the case, we should be able to see it always as we breathed it out, but it contains water in its invisible form of water vapour. When this meets anything cold it is condensed into water, hence on a very cold day your breath, or at least the water vapour in it, becomes visible.

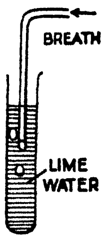


Fig. 458.

Exp. Take some lime-water in a test-tube and blow gently into it by means of a bent glass tube as shown in Fig. 458. The lime-water, which is clear like tap water, very rapidly becomes milky looking. This change is due to a gas called carbon dioxide. If a dish of lime-water be left exposed to the air, the surface will gradually become milky.

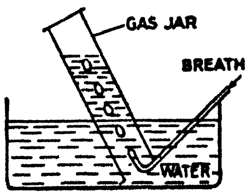


Fig. 459.

Exp. Half fill a trough with water and invert in it a gas jar full of water. Tilt the gas jar slightly, put beneath it the end of a bent glass tube as shown in Fig. 459, and blow through it. The breath will force the water out of the gas jar. When the gas jar is full of breath, place a glass slide over the mouth, while this is still below the water, and lift it out of the trough. Take a similar gas jar full of air. Into each gas jar in turn plunge a lighted taper and you will find that it is extinguished in the jar

containing breath, but burns in the jar of air. Flames cannot burn unless there is sufficient of the gas oxygen, and we may conclude that our breath does not contain enough oxygen for the taper to burn.

These experiments show that animal breathing adds a considerable quantity of both water vapour and carbon dioxide to the air, and also removes from it oxygen.

Respiration is an expensive process because it necessitates the breaking-down and ultimately the loss of complex organic substances. It is a katabolic process. It results in loss of dry weight. In order that health and growth may be maintained it is essential that the building-up of anabolic processes should be in excess of respiration. The excess of anabolism over katabolism is constructive metabolism.

There can be no activity without respiration. Thus the dormant spore or seed needs oxygen as well as water and a certain amount of warmth before germination can occur. All such resting bodies, which have the power of reawakening and starting new growth, have a supply of food to provide material for respiration so that a start in life may be made. Thus, when seeds germinate they lose in dry weight for a time, as a result of their respiratory processes. When, however, the aerial part has grown sufficiently to produce a green leaf the plant needs a supply of carbon dioxide and sunlight, then it begins to build up food for itself and add to its dry weight. As soon as photosynthesis has got a start, mineral salts will also be needed so that proteins, new protoplasm and chlorophyll may be formed, in short that growth may continue.

CHAPTER XXVIII

MOVEMENT AND LOCOMOTION

1. INTRODUCTORY

One is accustomed to think of plants being stationary bodies, and of animals as having the power of locomotion, that is, movement from place to place. We have seen that this distinction does not hold good when dealing with the lower forms of plant life, which live in water. Chlamydomonas is a plant, while Euglena is an animal, and both move actively in the water by means of cilia. It also has been noticed that land plants, *e.g.* Ferns, have retained a motile male gamete in connection with their sexual reproduction.

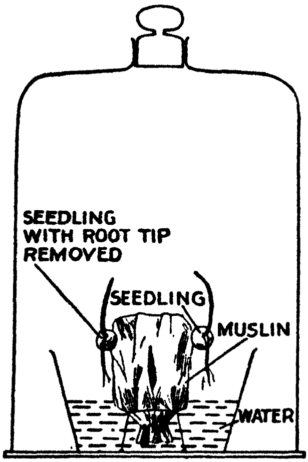


Fig. 460. To illustrate geotropism.

2. MOVEMENTS OF ROOTS AND STEMS

It is, however, movements connected with growth and protection which are more predominant in plants than locomotion. When a seed is planted in the soil, the root always finds its way downwards, towards the water and food material in solution in the soil, while the stem always makes its way out of the soil, growing upwards into the air and light, no matter how the seed was placed. Mustard seeds grown on sponge will all develop their roots downwards and their stems

straight upwards, as soon as possible, whatever the angle at which they are compelled to start.

EXP. When a large seed such as a pea or bean has germinated, so that a small root is present, make tiny equidistant marks on the root with a very fine pen and indian ink. It is important that the root be kept wet, otherwise it will shrivel, and a good plan is to place it on damp blotting-paper while marking it. Make the marks about 1 mm. apart. By means of a pin passed through the cotyledons of these seeds, fasten them to pieces of cork, and place their roots in any direction. Cover the cork with muslin dipping in water to keep the seedling damp, float the cork on water, and cover with a bell-jar as shown in Fig. 460. The seedlings will go on growing, the direction of growth of the root and shoot can be observed, also the position of the marks on them.

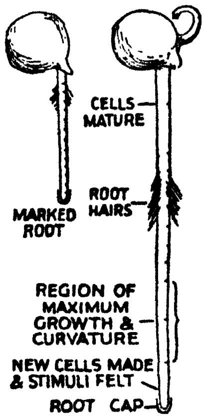


Fig. 461.
The growth of a root.

It will be found that the region just behind the root-cap is the place where the marks get farther apart, that is, where the root elongates most. It will also be seen that when curvature has taken place, it is in this same region that it has occurred (Fig. 461). This part of the root is known as the **region of maximum elongation.** The new cells are actually produced by cell division in the area inside the root-cap; but it is a little further back where they grow up and consequently cause rapid growth in length.

Similar experiments may also be performed with the stem, and a similar result obtained, but it is not quite so easy to get at the stem tip because of its covering of leaves.

If a minute piece of the tip of the root be either cut off, or rubbed off with a thimble, it will be found that the root

just goes on growing in the same direction for a little while, and does not curve to obtain a downward position. If, however, the root be placed horizontally, upside down, or in any other incorrect position for about twenty minutes, and then the tip removed, it will be found, however they are then placed, that they will curve in such a way that they have corrected the position in which they were before the tips were removed. From this we conclude that the tip is the part of the root which is sensitive and feels the stimulus of the incorrect position. A message is sent to the region of maximum elongation, where the necessary curvature takes place.

These experiments can be performed under normal light conditions, or in the dark, with the same results. The curvature is due to the influence of **gravity**, which draws the root towards it and repels the stem so that it grows away from it. The curvature is called **geotropism**, that of the root **positive geotropism**, and of the stem **negative geotropism.**

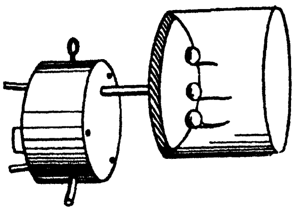


Fig. 462. A Klinostat.

The direct upward and downward direction applies to the main stem and root, the lateral organs grow out to some extent horizontally. This is known as **dia-geotropism.**

If the seedlings in our experiments be rotated slowly so that all sides of the stem and root tips experience the force of gravity evenly and successively, with no time to respond, they will continue to grow horizontally. This can be done by means of a **klinostat** (Fig. 462). The seedlings must be kept moist and the chamber containing them is rotated by means of the clock about once an hour.

In some plant organs the response to gravity changes during the period of growth. Poppy flower buds during their development to maturity hang down their heads,

because the top part of the flower stalk bends towards the earth, therefore it exhibits positive geotropism. Before the bud opens the stalk becomes erect, showing negative geotropism, so that the flower, and later the fruit, face up to the sky.

There have been several theories put forward to try and explain why plant organs curve in this way. It has been suggested that in roots, where there is no photosynthesis, the concentration of carbon dioxide produced by respiration is much greater than in stems; consequently the pH of the protoplasmic medium within the cells is different. Hence the electrical balance varies and the position of particles within the protoplasm will be influenced. Variations in the pH also mean variations in the permeability, and therefore turgidity, of the cells. It is interesting that roots can be induced to grow upwards in the dark, in a moist chamber rendered faintly alkaline by ammonia vapour. Stems can also be made to grow downwards in the presence of acetic acid vapour, or 30 per cent. CO_2, or in darkness if smeared well with vaselin so that the CO_2 of respiration cannot escape. In these ways the pH of the cell contents is altered. In all cases the roots and stems will resume normal growth when the condition is removed.

3. PLANT MOVEMENT IN RELATION TO WATER

The very great influence of **water** upon the direction of growth of roots may be shown by the following experiments:—

Exp. Put some moist fibre or sawdust in a sieve, place seeds in it, and suspend it at an angle so that the lower part keeps wetter. Note that the seeds germinate and that the roots reach the holes in the sieve, and emerge from them; but they only just peep through and then turn back again along the bottom of the sieve (Fig. 463). A sieve placed horizontally gives a control experiment.

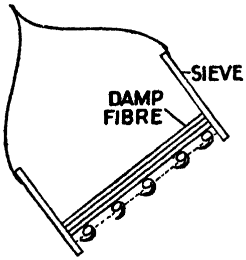


Fig. 463. To show hydrotropism.

The roots came through in response to gravity, but the air was dry, and in the slanting sieve water very easily won in the tug of war with gravity, and the roots kept in the moist material. In the horizontal sieve the moisture being distributed round them equally they were unable to decide which way to turn. The stems, feeling no such influence, grew vertically upwards in response to gravity.

Exp. Another method of showing the power of water over roots is to take a small flower pot, put a cork in the hole in the bottom, and bury it in a large vessel filled with fibre or sawdust (Fig. 464).

In the larger vessel plant some seeds as far away from the pot as possible. Pour water into the pot; this will gradually pass through the porous pot and spread through the fibre, but the area nearest the pot will remain the dampest. It will be found that the roots all turn and grow towards the pot, forsaking gravity.

This curvature of a root in response to water is known as **hydrotropism**.

4. PLANT MOVEMENT IN RELATION TO LIGHT

It is a well-known fact that plants grown in a window bend their stems towards the **light**, and place their leaves parallel with it; so that if it is desired to keep the plants straight they must be turned round quite frequently.

Mustard seedlings can be sown on a piece

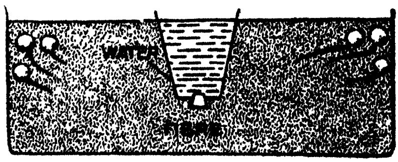


Fig. 464. To show hydrotropism.

of damp sponge, suspended in a beaker. If this is placed in a light-proof box, into which light is only allowed to enter by means of a small hole (Fig. 465), the hypocotyls begin to grow towards the hole, that is, towards the light, while the roots grow directly away from it. This is known as hypocotyl. **Positive heliotropism** in the stems and **negative heliotropism** in the root. Main stems react like hypocotyls.

White light is composed of a mixture of the seven colours of the rainbow, known as the spectrum, and some of these have more effect on plant life than others. When Hyacinths are grown in coloured glasses stood in windows, the roots always bend away from the light, except in those which are dark blue (Fig. 466). It is important to notice that gravity is operating in all these cases as well as light, and in the case of the dark blue glass it wins in the struggle, but otherwise a position is taken up at an angle, a position intermediate between that which would be produced by either influence alone.

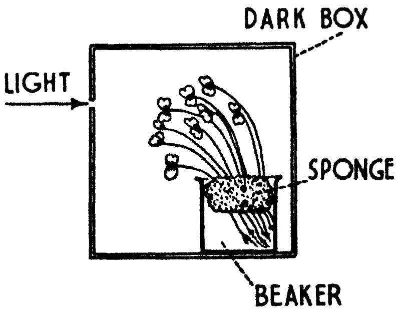


Fig. 465. Seedlings grown to show heliotropic curvatures.

As in the case of gravity, a klinostat can be used to eliminate the influence of light from one side, and no curvature will result. The tip also may be shown to be the sensitive part. Lateral organs are **dia-heliotropic.**

If plants are grown in a window, in a surprisingly short time, often less than twenty-four hours, the petioles all twist so that the blades are facing the window. By this arrangement the light is striking the blades perpendicularly, so that the upper surface of each leaf is receiving the maximum amount of light. Leaves in which the

blades assume this position with regard to the light are said to be **dia-heliotropic.**

Just as geotropism changes in some plants, so too, does heliotropism in others. Ivy-leaved Toadflax (*Linaria cymbalaria*) is a small plant growing in the crevices of walls, and spreading by means of its creeping stem. It has flowers like those of Snapdragon, only much smaller, and with a fairly long spur on the anterior side of the corolla tube (Fig. 467). These flower-stalks grow away from the wall towards the light, bringing the buds and flowers into good positions for obtaining sun and being pollinated. Evidently the stalks are positively heliotropic. When the fruit is ripening the stalks bend away from the light towards the wall, carrying the fruit by the time it is quite ripe, into a crevice where the seeds may be dropped when the fruit splits, and where they may germinate. The stalk is then showing negative heliotropism.

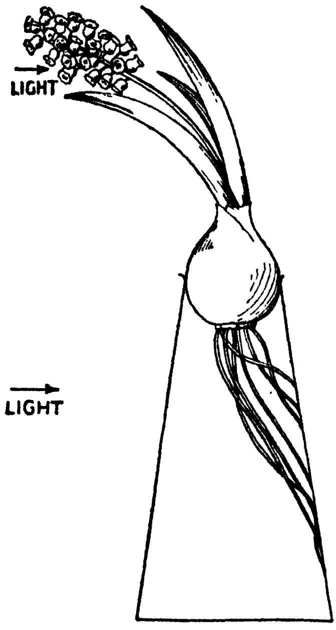


Fig. 466. HYACINTH.
Showing that stems are positively and roots are negatively heliotropic.

The fundamental need for stems and leaves to reach the light, and the value of heliotropism is seen in connection with some plants, which grow in hedges and which consequently have assumed **the climbing habit.** As the rate of the growth of the stem varies at different times and on different sides, it marks

out a spiral path. This is straightened by geotropism. In some plants this spiral is sufficiently large to include in its path some object which may behave as a support to the plant. In this way *Convolvulus*, Black Bryony

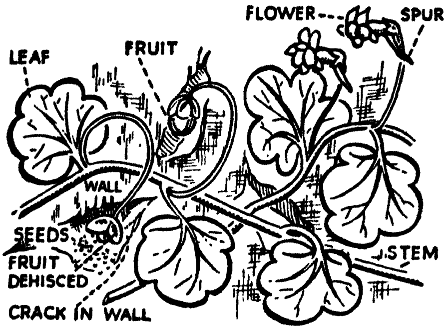


Fig. 467. Ivy-Leaved Toadflax.

(*Tamus*), Honeysuckle (*Lonicera*) and Hops (*Humulus*) twine their stems round branches of the shrubs and other structures in their path, and climb up in the hedges (Fig. 468). This habit is a great advantage to them, because they are enabled to elongate rapidly, as they can economise with regard to strengthening tissue since they use the strength of the support to hold themselves up.

Fig. 468. Climbing Plants.
A, Convolvulus stem twining against the sun; B, Hop twining in same direction as the sun.

Many plants achieve a similar result by modifying some part, such as some of the leaflets in Peas (Fig. 469), the whole leaf in *Lathyrus aphaca*, the stipules in *Smilax*, the lateral branches in White Bryony (*Bryonia dioica*) (Fig. 470), the ends of the main stems of a sympodium

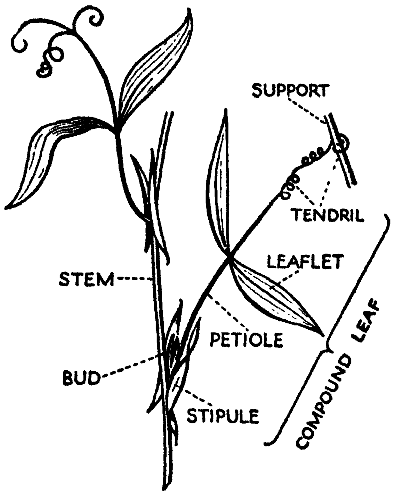


Fig. 469. Leaf of Meadow Pea.

in Vine (*Vitis*) and Virginian Creeper (*Ampelopsis*) (Fig. 471) into special climbing organs known as **tendrils.**

These are long and thin, with the tip slightly curved. The convex side of the curved tip is **sensitive to contact,** and will curve still more to hold quite firmly on to a support of such a size that it can grasp it. Having become attached to a support a stimulus travels along the tendril, so that the more central part of it coils up spirally, half the spiral being wound one way, and half the other. This spiral serves to draw the main stem towards the support, and also gives a great deal of elastic power to the tendril. The very thin, delicate tendril, so easily snapped whilst straight, is a very efficient spring when coiled, and responds to the action of the wind and weather generally, without breaking.

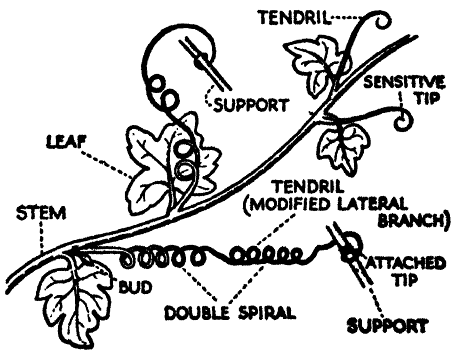


Fig. 470. White Bryony with Tendrils.

Some plants, *e.g.* Clematis and the garden

Nasturtium (*Tropaeolum*), have sensitive petioles, which coil round supports with which they come in contact.

If plants with twining stems are grown in the garden or in boxes, they may be given sticks of different thicknesses for support. It will be found that the stem cannot twine round sticks of very great thickness because the stem in rotating does not make large enough circles.

Supports of suitable thickness having been obtained, they may be placed at different angles to the horizontal from 90° downwards. The plants cannot utilise a stick placed at an angle less than 45°.

Experiments may often be conveniently performed with tendrils, even if the material used is not growing. White Bryony has large tendrils, which are easy to handle, and gives quite good results. Young tendrils must be used but they should show a curved tip. If the tendril is stroked with a pencil point or a very thin glass rod, inside the curve, in a few minutes it will curl round in a ring.

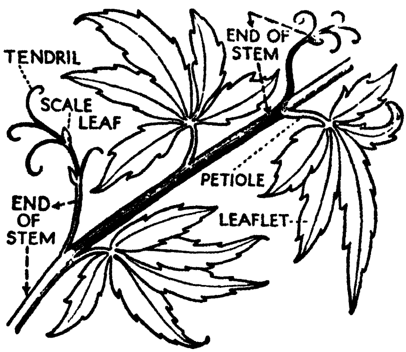


Fig. 471. Ampelopsis Quinquifolia with Tendrils.

The rod used for stroking must not be too smooth. If the end of a glass rod is dipped in hot liquid gelatine and then allowed to cool so that it has a smooth coating of solid gelatine, it will be found that stroking with this rod is not followed by any movement on the part of the tendril. To show that the tendril is sensitive, it should be stroked with the uncoated part of the rod, when curvature should follow.

5. THE SENSITIVENESS OF PLANTS

A striking example of sensitiveness to contact of special material, namely protein, is seen in **Sundew** (*Drosera*). This plant lives in bogs, where owing to the high percentage of humic acid present and general slowness of decomposition, food, particularly in the form of nitrates, is very hard to get. It has the rosette habit. The leaves have flat stalks, and the lamina is circular with the upper surface and edge bearing little red hairs with round knobs at their ends. These are known as tentacles (Fig. 472). Should a fly, or small piece of suitable protein material, such as boiled white of egg, arrive on a tentacle, a series of changes is set in motion. The tip of the tentacle sends a message to its base on the surface of the leaf to curve over and hold the insect: this message is broadcast from the base of the tentacles to all the others in the neighbourhood, and if it be a struggling fly which is caught, the message soon reaches all the tentacles and they curve over and hold it. In addition to this, cells of the tentacles have been stimulated to make and pour out a fluid to dissolve the fly's body. The tentacles continue this work until all the possible material is dissolved. The soluble material so produced is absorbed by special cells on the leaf surface. When no more use can be made of the fly, the tentacles again unfold so that the insoluble wings and legs may be blown away. The leaf is then ready to catch its next meal. This is in many ways comparable with the movements of the tentacles of such animals as Hydra in connection with catching food.

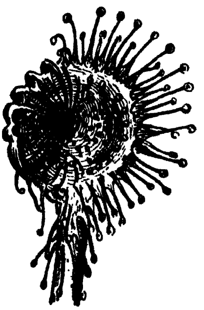


Fig. 472. LEAF OF DROSERA.
Tentacles expanded on the right; partially inflexed over an insect on the left.

A specially interesting example of plant movement is seen in the tropical plant, *Mimosa pudica*, commonly known as the **Sensitive Plant.** It has compound pinnate leaves with many leaflets, and each has a rather swollen

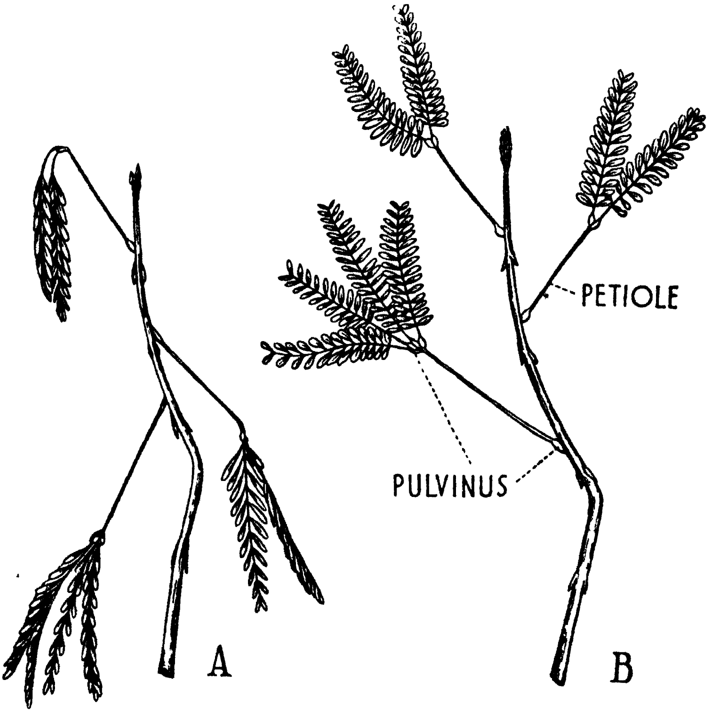


Fig. 473. The Sensitive Plant.
A, Leaves closed; B, Leaves open.

base known as a pulvinus. A similar swelling also occurs at the base of the petiole. If the leaflets are touched gently, they slowly fold together, and the stimulus gradually travels from those touched to others near them. If the stimulus is sufficiently great it will travel to all the

leaflets and ultimately to the leaf base so that the whole leaf will droop (Fig. 473). The same result may be obtained quickly by shaking the pot in which the plant is growing or treading sharply on the soil near the plant. This is a protective adaptation against herbivorous animals.

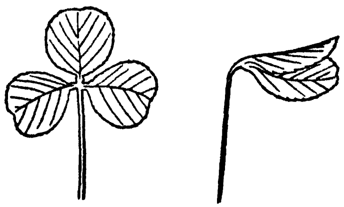


Fig. 474. CLOVER LEAF.

6. PLANT MOVEMENT AT NIGHT

There are many plants whose leaves or flowers assume a different position at night from that in the sunshine; they are said to go to **sleep**. Clover is a familiar example where the leaves perform this movement. Each leaf has three leaflets held erect on a long petiole, at the base of which two stipules are present. In the daytime the three leaflets are expanded horizontally to receive as much as possible of the sunlight and warmth. In the evening the two side leaflets droop and gradually move round so that their upper surfaces are in contact with one another. The third bends downwards over these two, folding in along its midrib and covering the others in a roof-like manner (Fig. 474). This arrangement provides less surface for transpiration, radiation, and the deposition of dew, and thus prevents too much lowering of the temperature. The upper surface of the Clover leaf being most active in giving off water vapour in transpiration, is by this method of folding specially protected.

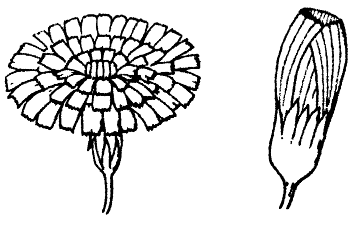


Fig. 475. DANDELION CAPITULUM.

In the Dandelion the capitulum closes up at night (Fig. 475). The florets assume a more vertical position, and the involucre of bracts also stands up around them in a position very similar to that in the bud. This particularly prevents deposition of dew, which might soak into the anthers and minute corolla tubes.

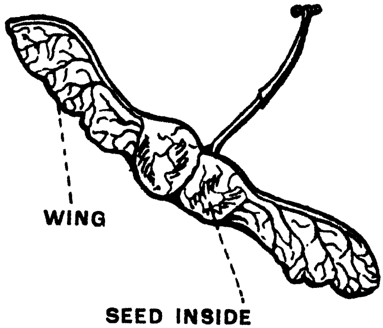


Fig. 476. MAPLE FRUIT.

It is always important that the pollen and stigmas be kept dry. For this reason many flowers, in addition to Dandelion,

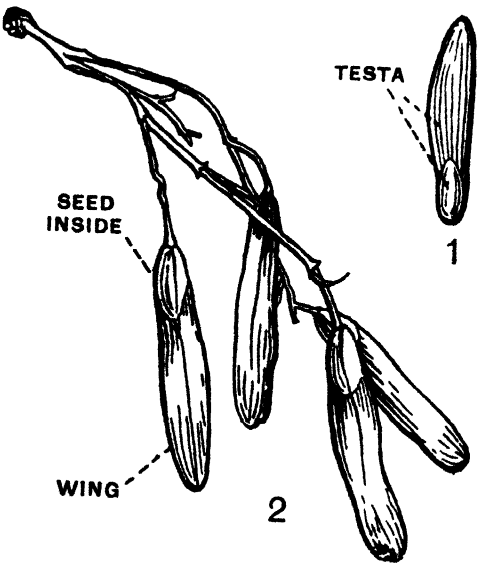


Fig. 477. 1. PINE SEED. 2. ASH FRUIT.

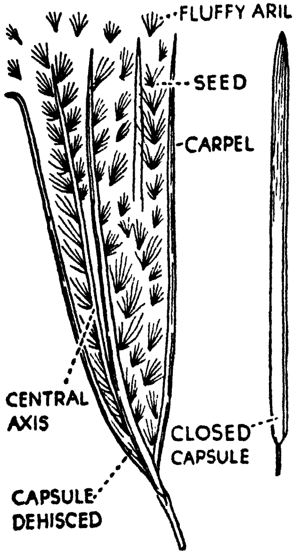


Fig. 478. WILLOWHERB FRUIT.

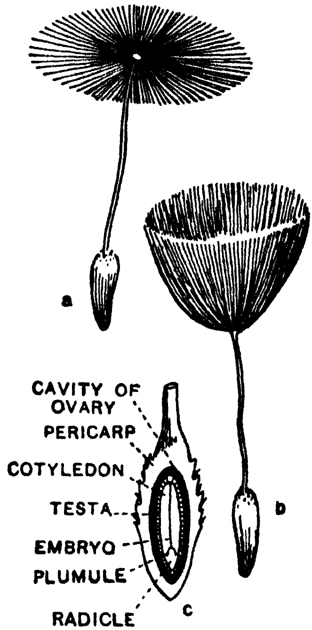


Fig. 479. DANDELION FRUIT (enlarged).

A, With calyx expanded; B, With calyx closed; C, Fruit in section showing the several parts.

assume a closed or drooping position when it rains as well as at night, *e.g.* Crocus, Tulip, Harebells, Scarlet Pimpernel.

7. PLANT MOVEMENT IN RELATION TO HEAT AND WIND

Some flowers also respond very readily to **heat.** Tulips very soon open under the influence of warmth, and may be induced to close again by lowering the temperature.

Many plants, particularly trees, disperse their seeds by the agency of the wind. They develop appendages either on the seeds themselves, *e.g.* Pines, Firs, Willowherb, Willow, and Poplar (Fig. 478), or the wall of the one-seeded fruit grows out and forms a wing, *e.g.* Ash, Elm, Sycamore, and Maple (Figs. 476, 477). In the last two, the complete fruit splits into two one-seeded portions. Other familiar examples of fruits which fly are Dandelions, Thistle, Groundsel, Clematis (Fig. 479). There is no activity on the part of the plant in connection with this locomotion. They are simply wafted hither and thither by the wind, their physical form being adapted to make this possible.

8. MOVEMENTS OF ANIMALS

Animals, on the other hand, have muscles, more or less complex according to the type of animal, by means of which they move from place to place in the media in which they live. Thus the earthworm burrows in the soil, fishes swim in the water, rabbits, dogs, sheep walk or run on land, birds and insects fly in the air as well as move on dry land. With the exception of the earthworm these animals have special appendages to assist in the necessary movements, thus fishes have fins and a specially constructed tail, while rabbits have four limbs; birds also have four limbs, the front pair being specialised and known as wings, while insects are very well provided with both legs and wings.

CHAPTER XXIX

SAPROPHYTES

1. INTRODUCTORY

A normal green plant, as already shown, takes its food from soil and air in the form of simple, inorganic substances, which it builds up into complex organic compounds. The type of plants, known as parasites, which obtain the complex organic substances already built up from other living plants, has been noticed. Another source from which to obtain these organic substances is obviously a dead plant, instead of a living one. This furnishes a group of plants with another method of nutrition, and these are called **saprophytes.** The saprophytes with which we are familiar in this country are very simple in form and belong to the group known as **Fungi.** Perhaps the most complex structures to be found in the group are mushrooms and toadstools, and these consist of a tangled mass of filaments only. Many fungi form mould on such things as damp bread, jam which has too much water in it, or decaying materials in soil. Their reproductive bodies, in the form of microscopic spores, are always present in the air, and germinate as soon as they settle on a suitable food medium.

2. MUCOR

Pin-mould, or **Mucor,** is a white mould. It consists of a multinucleate thread-like structure with a very thin, delicate membrane, surrounding the protoplasm, and many small nuclei. This thread grows, elongates, and branches. Some of the branches ramify, as it develops, into the material upon which it is feeding, and others form eventually

a dense mass on the surface very much like a mass of cobwebs (Fig. 480, A). After a while these patches of soft, white, silky threads become studded with a number of small, black dots, held erect above the surface, from the appearance

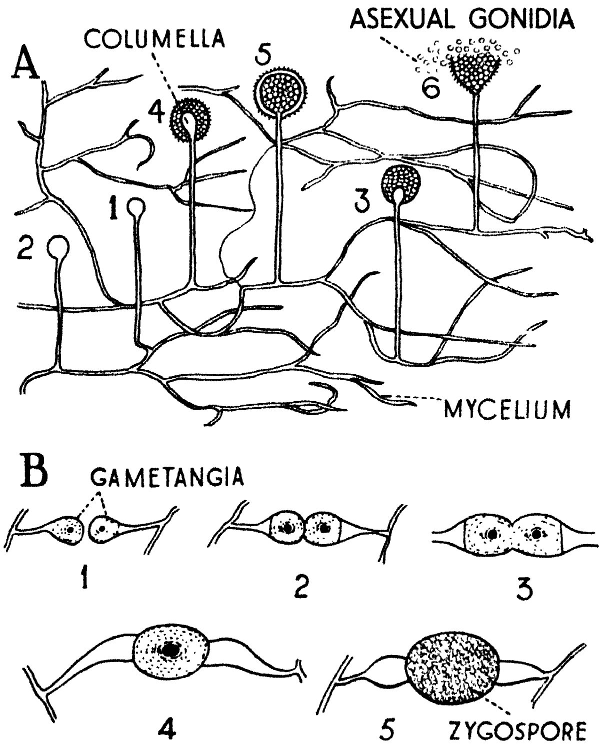


Fig. 480. MUCOR.
A, Stages in development of asexual gonidia; B, Stages in development of zygospore.

of which the plant gets its popular name, "pin-mould." These heads are reproductive bodies, each being a case full of minute bodies called gonidia, each of which is capable of producing a new plant. The black colour is due to a

number of crystals of calcium oxalate, which are secreted on the surface of the case as the gonidia mature. Owing to the production of mucilage by the enlarged tip of the thread, known as the columella, the somewhat brittle wall is ruptured and the gonidia set free. Some of these may fall near by, others be carried by the wind, insects, or small animals, and if they reach a suitable situation they germinate very rapidly and form new Mucor plants.

This fungus can easily be cultivated on damp bread. It is only necessary to expose the bread to the air a little while and then keep it moist under a cover, such as a bell-jar, and it is quite easy to watch this mould develop, and the bread decay. When the supply of nutrient material is becoming poor, and other substances resulting from the life of the mucor plants have accumulated, reproductive bodies are formed, which are better able to withstand adverse conditions. Embedded in the subtratum, the ends of two threads come in contact with one another (Fig. 471, B), and a kind of sexual union results. The contents of the two cells are gametes and they fuse to make a zygospore. Zygospores are larger than the gonidia. contain a supply of food and are covered with a thick, rough, black coat. This zygospore can rest for a prolonged period and has opportunity for being conveyed to a fresh field of activity by wind, insects, worms, or other agents. On germination it forms a sporangium containing spores formed by reduction division. These produce mycelia. Two distinct mucor plants are needed to effect sexual reproduction, so that one plant behaves as a male plant and needs to find a female one with which to unite, although no external difference is visible. By this combination new strength is perhaps acquired.

3. EUROTIUM AND PENICILLIUM

The Blue Moulds, **Eurotium** and **Penicillium**, also occur on damp bread, jam, and similar materials. Like Mucor,

they form a mass of threads, which penetrate into the material and decompose the original body substances. This mycelium, however, consists of a number of cells, that is, it is septate, there being transverse walls in the hyphae (Fig. 481). The methods of reproduction are also different from those of Mucor, consequently they belong to a different group of fungi; Mucor belonging to the Phycomycetes or Algal Fungi, while Eurotium and Penicillium

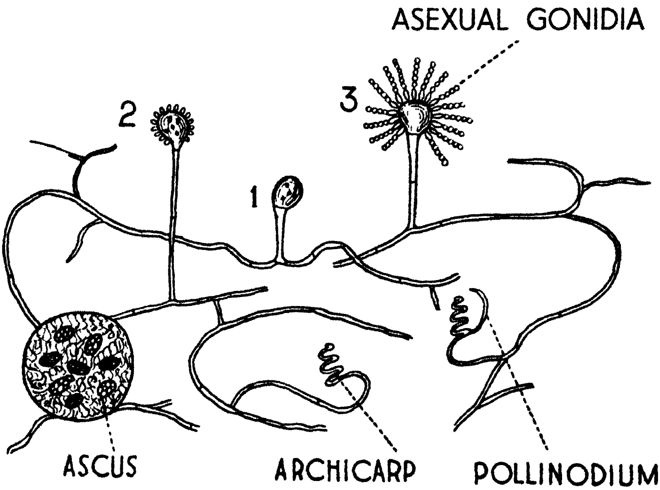


Fig. 481. Eurotium.
1, 2, 3, Stages in development of asexual gonidia.

belong to the Ascomycetes. The aerial branches produce gonidia but not in a case.

In Eurotium the end of a hypha becomes swollen and multinucleate, at first resembling Mucor, but over its surface numerous small papillae arise. Several nuclei pass into these small projections which elongate and form little rod-shaped structures, known as sterigmata, and from these chains of gonidia are abstricted (Fig. 481). The gonidia have several nuclei, their walls are greenish in colour and

they germinate rapidly to form new plants. In Penicillium the erect hyphae become verticillately branched in either twos or threes and from these branches gonidia are abstricted in chains (Fig. 482). Later, in the subtratum, certain thin branches of the mycelium become coiled and form a female organ, known as an **archicarp** (Fig. 481), which consists of three multinucleate portions, the terminal one being the trichogyne, the central the ascogonium, and the basal the stalk. A branch which is the male organ, known as the **pollinodium**, grows up by the side of the archicarp.

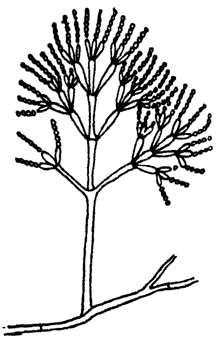


Fig. 482. Penicillium Showing Asexual Gonidia.

The pollinodium touches the trichogyne, the wall between them breaks down, and the contents of the two organs probably fuse. Numerous multicellular branches grow up from the stalk around the archicarp and form a false tissue, pseudo-parenchyma, completely enclosing it. The **sexual union** apparently stimulates the ascogonium to give off a number of multicellular branches. In the last cell but one of each of these branches the two nuclei that it contains fuse; so that to restore the correct number of chromosomes two reduction divisions are needed. One occurs, giving four nuclei, and these four each divide so that the chromosomes are reduced; but this one is not, as is more usual, followed immediately by a further division to complete it. (See Chapter II.)

Thus each of these special cells contains eight nuclei, each surrounded by a little portion of protoplasm. A wall then develops round each and eight **ascospores** result. The cell-wall containing them is called an **ascus** (Fig. 481), and they are said to be formed by free cell formation. There is a little protoplasm in the ascus which is not used up in their formation. All the pseudo-parenchyma, except

just enough to form a case, disappears. Eventually the ascospores are freed from the asci, and then there remains a yellowish, brittle case containing a number of ascospores. When these are set free they may rest or may germinate immediately to form a new mycelium. The first nuclear division that takes place on germination must be considered to complete the second reduction division which occurred during spore formation.

4. SACCHAROMYCES (YEAST)

Saccharomyces or **Yeast** is a unicellular organism which possesses no chlorophyll, but lives on organic material which it causes to ferment. Wild yeast occurs on the skin of grapes and causes fermentation if the skin becomes broken. It is a somewhat oval cell, consisting of a cellulose cell wall enclosing cytoplasm, a nuclear apparatus, vacuoles, the carbohydrate glycogen, and other food granules. The nuclear apparatus consists of a vacuole containing a granular chromatin network and a nucleolus (Fig. 483). The nuclear apparatus becomes constricted into two parts, and then the cytoplasm collects around the two parts and the wall grows in so that a small swelling or bud is produced (Fig. 483). This small cell is eventually

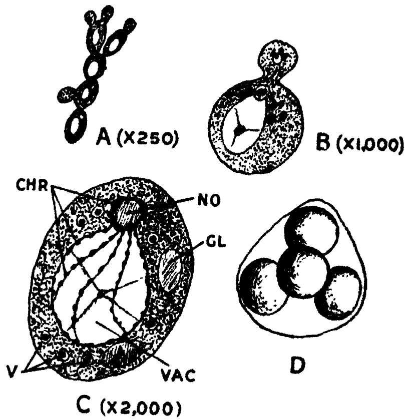


Fig. 483. Yeast.

A, Chain of cells, budding; B, A cell budding; C, Composite diagram from variously stained preparations (after Wager). NO, Nucleolus; CHR, Chromatin; GL, Glycogen; VAC, Nuclear vacuole; V, Volutin granules; D, Formation of four resting ascospores inside a cell.

"budded off" from the parent cell and grows to its full size. Thus two cells are produced by a vegetative division, each of which is really a whole plant.

This process takes place very rapidly, and a very large number of plants are thus produced in a short time if conditions of growth are favourable. When, however, the food supply is getting depleted, the nuclear apparatus divides into four, each of which becomes surrounded by protoplasm and then by a cell wall. The remainder of the protoplasm gradually disappears as these structures mature until there seem to be four spores in a case or sac, called **ascospores** in an ascus, because they are formed like the ascospores in Eurotium, although no sexual union occurred previous to their formation. These spores rest during unfavourable periods and then each one becomes a new vegetative plant, carrying out all the life processes of the organism.

Fundamentally yeast ferments sugar, and therefore requires a supply of sugar in order to grow. Only a very little sugar is used to build up new protoplasm, but it is capable of changing large quantities of sugar by **fermentation.** It can be induced to produce ascospores by placing it on slices of potato, which contain starch and not sugar, or only very little of the latter. Starch, although an allied substance, is insoluble and therefore difficult to utilise, consequently the yeast assumes its protective and enduring reproductive form.

A reducing sugar, for instance, glucose, is converted into alcohol and carbon dioxide, in accordance with the equation $C_6H_{12}O_6 = 2C_2H_6O + 2CO_2$. This can be carried on without oxygen being present. It is well known that the fermentation of beer, for example, goes on best in large vats where the supply of oxygen is low, but it must be realised that fermentative activity does not necessarily mean growth. Yeast requires oxygen for normal respiration in order to be able to grow freely; but it ferments

substances by the metabolism of living without necessarily growing at the same time. Since fermentation supplies yeast with energy it is a form of respiration, and because oxygen is not needed is called **anaerobic respiration**, while normal respiration is aerobic. Fermentation is actually caused by an enzyme contained in yeast, and can be brought about by an extract of this just as readily as by live yeast. Yeast ferments many substances in addition to glucose, and several enzymes have been isolated from it, by virtue of which this is brought about, *e.g.* invertase, which causes the hydrolysis of cane sugar, thus: $C_{12}H_{22}O_{11} + H_2O = 2C_6H_{12}O_6$, that is to say, one molecule of cane sugar by the addition of water is converted into two molecules of glucose.

By a very simple experiment it can be shown that alcohol and carbon dioxide are produced by yeast living in a sugar solution. Put the yeast and the sugar in a flask fitted with a one-holed cork and a delivery tube bent at right angles, and leading into a little lime-water or barium-hydrate (baryta water) solution. After a while bubbles may be seen rising in the lime-water or barium-hydrate solution which then very soon becomes cloudy, indicating the presence of carbon dioxide. If, after a time, a little of the liquid in the flask be distilled, alcohol may readily be detected by its smell in the first portion of the distillate; or its presence can be demonstrated by adding a little iodine dissolved in potassium iodide, and then putting in caustic potash until the colour produced by the iodine disappears, when a yellow precipitate and a characteristic smell, due to iodoform, will be obtained.

There are many species of Saccharomyces, and it is an organism of very considerable economic importance. It is used in the preparation of beer, ginger beer, and many other commercial products. When yeast is mixed with the dough in bread-making it is the CO_2 given off which is important as this causes the dough to rise.

CHAPTER XXX

BACTERIA

1. GENERAL CHARACTERISTICS

A multitude of living things, too vast and mighty for us to number, too small for us to see with our unaided eyes, is all around us and within us, we cannot get away from them, they are everywhere, in fact associated with Life and natural conditions of Life. The revelation of this life has gradually come to us since the middle of the last century. The knowledge of its existence waited the production of a compound microscope, the possibility of magnifying considerably small things, and since then step by step there has been found a world of life previously invisible to us, yet so important, playing such a vital part in the earth, that not only our well-being but our very existence depends upon it.

Most of the life in this mighty army consists of bacteria in their multitudes of different kinds of activities. They have come to be known by their effects, and have been cultivated under somewhat varying conditions of temperature and on different nutrient media, where they are recognised by the form and colour of the growth they collectively produce under particular circumstances.

Bacteria are studied by means of pure cultures. Media and conditions which are most favourable for one kind may be less favourable for others, so that the former will grow more rapidly. A drop from a liquid culture may be taken and diluted very considerably with boiled distilled water, care being taken to use only implements which have been sterilised previously by heating. If a drop of the diluted culture be run over the surface of a medium, containing agar-agar to render it solid, in a petri-dish, colonies may be

obtained. If only one little organism settles in one spot and grows to form a colony, that colony will be a pure colony, and can be used for further growth.

Bacteria are of three primary shapes, a straight rod or bacillus, a spherical form or coccus, and a twisted form or spirillum (Fig. 484). They are so small that 10,000 of them would need to be placed end to end to make one inch. It would take at least 500,000,000,000 to fill a thimble. Some of them have cilia, by means of which they move

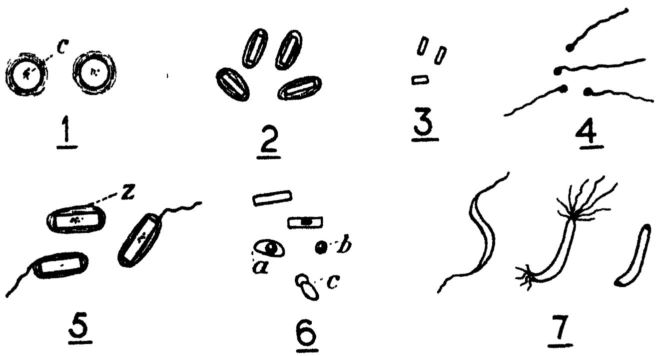


Fig. 484. BACTERIA.

1, Azotobacter (c, central body); 2, Bacillus radicicola; 3, Nitrobacter; 4, Nitrosomonas; 5, Bacillus subtilis (Z, Zooglea); 6, Bacillus anthrax (a, Spore in rod; b, Spore; c, Spore germinating); 7, Spirillum.

about rapidly. They make up for their small size by their rapidity of multiplication. When conditions are favourable for their development, one becomes two in twenty minutes, two become four in forty minutes, and four become eight in an hour. These would become sixty-four in two hours, 4,096 in four hours, approximately 16,000,000 in eight hours, and in one month there would be an army which would occupy more than the volume of the earth if they all survived and multiplied at this rate.

When we consider their small size and rapid multiplication, we need not be surprised that the theory of spontaneous generation was held for so long. Aristotle noticed that when conditions were changed from wet to dry and vice versa, life frequently appeared in what had previously appeared to be a lifeless medium. We now do not need to suppose that life arises under these conditions, we know it to be there in microscopic form, ready to develop and become visible if circumstances permit.

Each bacterium is a very small cell, consisting of a colourless protoplasmic body, in which there is a granular central body forming a somewhat reduced nucleus. This living body is enveloped in a delicate cell wall, outside which is a gelatinous covering, known as a zooglea. The presence of the latter causes them to stick to a microscope slide if slightly warmed and allowed to dry, so that they can readily be stained and mounted for examination.

2. THE WORK OF BACTERIA

Bacteria individually, except with microscopic aid, we do not see, yet we are all familiar with some effects of their presence, some results of their lives. Have you ever wondered why and how the tropical forest and the familiar woodland go on and on, year after year, the dead and waste material disappearing, so that they are always fresh and habitable, and the food supply never failing?

The fossils, which provide records of past ages, and are so valuable in assisting us to build up the genealogical Tree of Life, are present in the rocks, owing to inhibited bacterial action, and similarly mummies have been preserved; but generally life goes on, ever changing yet ever renewing that which is temporarily lost. Any part which has ceased to live, whether plant or animal, also their excreta, any article of human food, which has its origin in plants or animals, is pounced upon by an ever ready army

of **saprophytes** and gradually decomposed. Thus sets in the process known as putrefaction. Food, which has been kept too long or unsuitably stored, becomes unfit for human consumption, because we have been forestalled by myriads of creatures we did not see.

Some decomposition bacteria, like yeast, are **anaerobic. Bacillus subtilis** (Fig. 484), which lives on hay, is a well-known example. If the hay is not dry when the hay-stack is built, it may set fire to itself in the centre. This is due to the heat produced by the activity of bacteria, which, in the presence of the moisture, are actively decomposing the hay. These organisms appear in an infusion of hay, which has been kept for a few days. They are fairly large and rod-shaped with one cilium. When the hay has become changed in character by their activity they develop a large zoogleal covering and hold together in masses.

In Nature this is not the end, but the beginning of a great cycle of changes, because every new substance made by the putrefying bacteria is just as vigorously sought and changed by other forms, until the process of breaking down becomes changed to one of building-up, and gradually step by step materials which can be utilised by the higher forms of life are again produced. Th s the protein of the dead or waste material is decomposed with the liberation of ammonia. This is a gas with a characteristic smell, which is noticeable if you are near a manure heap. Some of this gas escapes into the air, but it is very soluble in water: therefore some remains, and that which has temporarily escaped into the atmosphere is dissolved by the rain and washed back into the soil. Ammonia contains nitrogen, but in this form it is not directly useful to the flowering plants. There are, however, bacteria known by the generic name **Nitrosomonas** which use ammonia as their source of energy and convert it into nitrites. There are other bacteria, **Nitrobacter,** which eagerly seize upon the nitrites and change them into nitrates. These two bacteria

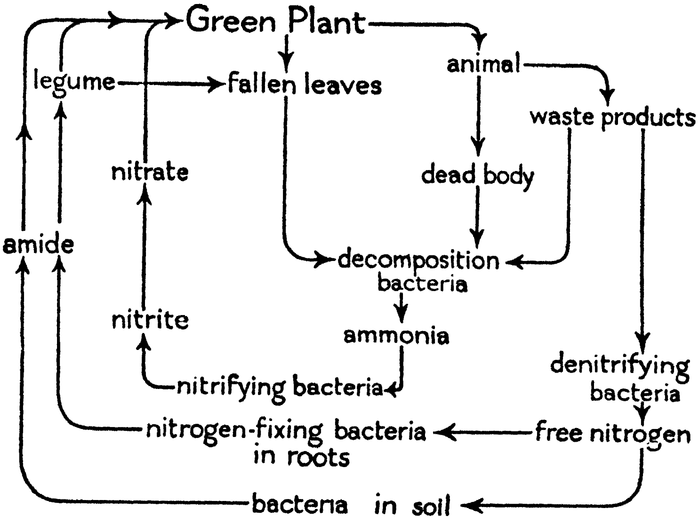
(Fig. 484) are together known as nitrifying bacteria. They change the ammonia of decomposition into the form of nitrogen sought by most normal plants, namely, nitrates. By this process some of the apparently useless dead material is so changed that it has become good food and will once again enter a living body.

Not only is **nitrification** useful from this point of view, but this is one of the changes that takes place in connection with sewage.

In 1877 Schloesing found that by passing a definite quantity of sewage regularly through a filter prepared from sand and powdered limestone, the filter would gradually acquire the property of causing the complete conversion of the organic matter of the sewage to inorganic materials which are not only harmless and inoffensive, but useful, because amongst them are nitrates which are valuable to plant life. This was found to be entirely due to bacterial action; the living organisms having been introduced with the sewage gradually accumulated in the filter until they were sufficiently numerous to alter completely the amount supplied as it passed through. This principle has been extended to-day into a vast system of drainage and sewage farms, so ·uɔɪ· millions of people may live crowded together in cities, as in London, under perfectly good hygienic and sanitary conditions, which enable them to maintain their health. The existence of large towns and cities would be an impossibility without bacteria. The value of improved and improving sanitation is well known to everyone, in the promotion of health, better conditions in which to live, and therefore happiness.

The nitrifying bacteria can be cultivated in a medium containing:—·2 grm. ammonium sulphate, ·02 potassium hydrogen phosphate, ·03 magnesium sulphate, ·05 sodium carbonate and 100 c.c. of water. They are both very small. Nitrosomonas is rod-shaped, and nitrobacter a coccus with a very long cilium. They develop very slowly in culture media.

These changes may be briefly tabulated as indicated below:—



This graphic scheme will be seen to include the nitrogen-fixing and denitrifying bacteria which also take part in the nitrogen cycle.

The nitrifying bacteria, by the energy exchanges occurring when ammonia or nitrite is oxidised, are enabled to use carbon dioxide as their source of carbon. Thus they are entirely independent of organic compounds, like the autotrophic green plants. For this reason they too are said to be autotrophic. They are also said to obtain their carbohydrates by chemosynthesis not photosynthesis. They normally live and work in the dark.

During the decomposition of protein, sulphuretted hydrogen, a gas with a very unpleasant odour is also liberated. For this an army of bacteria, known as **sulphur bacteria,** are waiting ready to pounce on it and decompose it. They store the sulphur temporarily in their bodies as

little globules, ready at some later date to be oxidised into sulphates during the metabolism of the bacteria. In this cycle too the sulphates are the chief source of sulphur to ordinary plants.

3. BACILLUS RADICICOLA. SYMBIOSIS

If a Clover root be dug up and carefully examined, it will be found to have a number of small swellings on it, which are quite characteristic (Fig. 485). These are called **root nodules,** and they are full of bacteria.

The bacteria in the clover root nodule are rod-shaped (Fig. 484). Their name is *Bacillus radicicola*—Bacillus because they are rod-shaped, and radicicola because they live inside cells made by roots. The bacteria which are present in the soil come in contact with the root hairs, and are allowed to make their way in. The cells inside the root are stimulated to grow and make the nodule for the bacteria to live and multiply in. These particular bacteria have the power of using the free nitrogen of the air and bringing it into combination in a compound; for this reason they are called **nitrogen-fixing bacteria.** Nodules are only made when nitrogen-fixing bacteria are present in the soil, and when they are formed, clover plants can grow in soil very poor in nitrates. These organisms are easily cultivated in a medium containing 1 grm. sugar, 0.25 grm. potassium hydrogen phosphate, 0.02 grm. magnesium sulphate, 0.5 grm. chalk, 100 c.cm. distilled water. They grow best if kept at about 34° C.

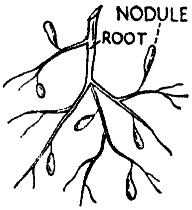
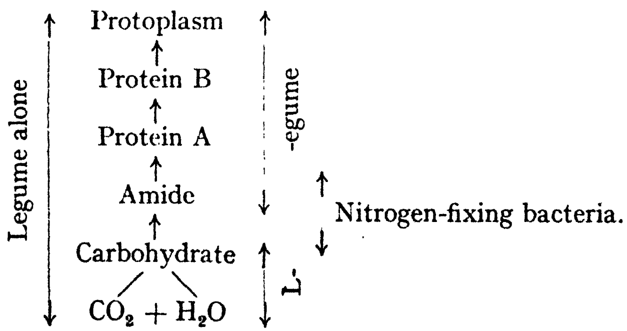


Fig. 485. CLOVER. Root with nodules containing nitrogen-fixing bacteria.

The substance made by the bacteria belongs to the class of compounds known as amides and contains carbon, hydrogen, oxygen, and nitrogen. The first three of these

elements are obtained from the Clover plant in sugar. The Clover is a green plant and builds up its protoplasm, like other plants containing chlorophyll, from carbon dioxide, water and mineral salts, as described in the last chapter. The bacteria have no chlorophyll, and are not in a position to get sunlight; therefore they will not be able to carry on the process of photosynthesis and build up sugar themselves. The Clover therefore supplies them with sugar enough for their own bodily needs, and a supply to build up into amides, which the Clover is able to utilise. It is thus seen, that although they have to make a little extra sugar for the bacteria, the Clover plants benefit by making these little factories and homes for the bacteria, because they never have to climb up one step of the food building ladder themselves. In this way a good deal of energy is saved which can be used for some other purpose, such as extra growth or early flowers and fruit.



This is an example of two kinds of plants living together in perfect harmony, making one community where each gives something and each receives something, thus both benefit by their mutual association. Such an arrangement is called **symbiosis** (Lat. *sym* = together: *bios* = life). It is because of this mutual benefit that Clover can grow

in very poor soil quite successfully, and is therefore a useful crop to grow one year, in series with other plants.

Ever since there has been any record of man and his doings, he has cultivated crops for food, and from the earliest times has grown different crops on the same piece of land in succeeding years: that is, he has practised the idea of "rotation of crops." Until this present century this was done because as a matter of experience it gave the best results, and it has always been customary to include a plant like Clover which has formed a symbiotic association with these nitrogen-fixing bacteria. It is now known that such plants do not take nitrates from the soil, but leave their nitrogen supply to enrich it.

In addition to Clover, Peas and Beans and many other plants have discovered the value of symbiosis with *Bacillus radicicola*, and benefit by it. These plants have many other points in common, such as their flower structure and that of their fruit, which resembles the familiar pea-pod. Such a fruit is called a legume, and it is usual to call the whole family of plants, which have these similar characteristics, legumes.

Nodules, for the same purpose, also occur on the roots of some plants which are not in this family; amongst them are Alder (*Alnus*), Buckthorn (*Elaeagnus*), Sweet Gale (*Myrica*), New Zealand Pines (*Podocarpus*), and Cycads.

In addition to these symbiotic nitrogen-fixing bacteria there are others which live quite freely in the soil. Amongst the most common of these is **Azotobacter** (Fig. 484), which is interesting because it is one of the largest bacteria known. It is a coccus in form. It can easily be cultivated in the medium given for *Bacillus radicicola*, substituting mannite for sugar. It is then easily recognised because it produces a brown scum in the solution. If grown on agar-agar the colonies are also brown, becoming darker as they get older.

4. ARTIFICIAL MANURES

It is interesting to notice that where crops are grown and removed from the land, it is necessary to supply manure from time to time, to restore some of the material removed by taking away the crop. In 1840 Liebig demonstrated the possibility of supplying the necessary substances in the form of chemical salts, which have become known as artificial manures.

The practice of adding artificial manures to the soil became so popular that in 1900 Sir W. Crookes, having estimated the amount of the nitrate used in this way each year, and the amount of nitrate available in the only known large, natural sources of supply, namely the nitrate beds of Chili and Peru, predicted a nitrogen famine. We need, however, have no fears for our wheat, and therefore our bread supply on this account, because as work in the present century has shown, the bacteria step in and save us.

5. AUXIMONES

At the beginning of the present century it was demonstrated that food is not the only thing needed for really good development. Vitamins in connection with animal and human life have become almost a by-word, it is, however, less well-known that plants respond to their own particular vitamins, called by Bottomley **auximones** or growth-promoters. These substances are the result of bacterial activity, being produced by the decomposition of peat and probably by all processes of manurial decay. Although good temporary results may be obtained from artificial manures, it is well known that after a time the soil becomes " sour," and the plants unresponsive, and may even deteriorate, whilst farmyard manure or some natural substance submitted to the process of decay gives continued good effect. The

presence of auximones gives better quality produce from every possible point of view, including macroscopic, microscopic, and earlier maturity.

6. THE WORK OF DAVAINE, PASTEUR, AND LISTER

Bacteria are frequently regarded as belonging to the realm of disease. So they do, but not there alone. We notice disease and ill-health, and are concerned by them, but good health, the birthright of us all, is neither noticed nor appreciated by the majority of the human race until it is lost. Let us not forget that among the active agencies in helping us both to keep and regain when necessary this precious gift, are bacteria.

It is interesting to notice that the first parasitic or disease-producing bacterium was discovered in 1854 by the French pathologist, Davaine. It was the Anthrax Bacillus which causes the much dreaded cattle disease and at times claims so many victims. Following closely upon this came the great work of another Frenchman, Louis Pasteur, and that of his British contemporary, Lord Lister, whose names have been immortalised as two of the greatest benefactors of mankind, because they have led the way towards so notably relieving human suffering. Pasteur demonstrated conclusively that many diseases, notably gangrene and erysipelas, which claimed so many victims in times of war, were entirely due to bacteria. When no bacteria were present a wound, which was not in a vital part, healed up cleanly and quickly with very little suffering relatively on the part of the patient. Lord Lister, working upon the great discovery, endeavoured to find some way in which, in spite of their great resisting power to external forces, the bacteria might be kept from developing. This was no easy task because such things as would poison the bacteria were also injurious to the flesh. Nevertheless, gradually he built up such a system of sterilising the

instruments, bandages, hands, and clothes of the operator, and of applications to the wound of weak carbolic acid, which was therefore the first antiseptic, together with free access of fresh air and sunshine to the patient, that he saw the death rate in the hospitals reduced from 45 per cent. to 15 per cent.

These two pioneers having led the way, rapid strides have been made in surgery during the last fifty years; and one by one, most of the familiar diseases have been shown to be due to bacteria. It is also important to realise that when the cause is definitely established it is much easier to find a method of cure and means of prevention. "Set a thief to catch a thief" is a principle which promises very good results when applied to curing and promoting immunity from disease. Three methods of using bacteria have been adopted:—inoculation with an allied culture, which proved so valuable in stemming the tide of smallpox; injection with a dead culture, or a toxin, because all living creatures poison themselves with their own products in time, unless they are removed; this has been successfully used for enteric fever; injection with anti-toxins, which are antidotes to the poison produced by the growth of the bacteria, has greatly reduced the mortality from diphtheria.

7. THE PRESERVATION AND DESTRUCTION OF BACTERIA

There are bacteria adapted to live in every conceivable situation; they live in the sea, as well as in fresh water, they remain unharmed when the pond freezes, some are to be found inhabiting hot springs, where the temperature is about 72° C. Many of them have the power of making spores by contraction and rounding off of the living contents of the cell and then protecting them with a wall (Fig. 484, 6). In this form they are remarkable for their great resisting power, in spite of the fact that there appear

to be no male and female cells and therefore no sexual reproduction. They are capable of withstanding very big periods of drought and starvation. Temperature changes have a considerable effect upon their activity. Many of them are killed at 55° C., and many more at 100° C., the temperature of boiling water. This is very useful in connection with food. Milk, for instance, can be subjected to the lower temperature and thus its bacterial content is materially reduced without destroying the valuable properties of this liquid. Boiling allows the possibility of preserving food, such as fruit, vegetables, fish, meat, in tins and jars for considerable periods. For this purpose sterile receptacles are used and the material subjected to the action of steam, or boiled, and then hermetically sealed. The material is just freed from bacteria and as their access is prevented, remains quite good. During recent years there has been remarkable development in this industry, and such products have gradually, but surely, gained much public favour. Fruits ripened in their native land can be canned there, bringing to the consumer a somewhat different product from the one he gets when the fruit is plucked in a very unripe state, packed, and ripened on its journey, away from the plant which bore it, away from the air and sunshine which normally assist in the process, as well as all sources of food. These differences are quite noticeable in pineapples, peaches, apricots, and so on.

Some bacteria are extremely resistant to changes of temperature, their activities being suspended temporarily, but their bodies remaining quite unharmed. They simply wait for the return of more congenial conditions. An outbreak of anthrax in the South of France was traced to cattle which had died twelve years previously and been buried twelve feet deep. After the death of the cattle the bacteria had assumed the spore form and gradually been brought to the surface again by earthworms. Many

bacteria have no objection to being boiled, and some have been placed in liquid air, that is, at a temperature of 182° C. below freezing point, without being harmed.

It is important to notice that they are much more susceptible to the influence of light. Some bacteria, which cause phosphorescence on the surface of meat and fish, were kept by Dewar for several months at the temperature of liquid air, in the dark, and they remained quite unharmed, multiplying apace when thawed, and giving the usual characteristic results of their activities. When however, he submitted some to the action of light, they were killed, being unable to endure the cold and the light. Sunlight generally is a deadly enemy to bacteria, particularly the violet rays which take part in the formation of the rainbow and the composition of white light. Here is an obvious reason why sunlight is beneficial to the human body. This has also been utilised in connection with our water supply. Our drinking water has a very long journey from the clouds as rain, and then possibly down many miles of hill and mountain side, and still more in the river, during which time it collects many materials both living and dead, soluble and insoluble. It is therefore generally advisable that the water should be purified to some extent. This having been done, storage is necessary, and large open reservoirs, with considerable surface exposed as much as possible to the direct rays of the sun are used, so the bacterial content may be kept as low as possible, by what may be considered natural means.

At every turn life is wrapped, as it were, in a spider's web of bacteria, some indeed disease organisms, but hosts upon hosts of others, which are waiting inside and outside our bodies to help us fight our battles.

CHAPTER XXXI

ECOLOGY

1. ENVIRONMENT. FLORA AND FAUNA

Much information and understanding can be acquired by making a study of plants and animals in their natural surroundings, and this is the science of ecology. They are affected by the climate, the soil, and one another, in other words by their general **environment,** and they form communities living together in definite **habitats.** The plants of a habitat constitute the **flora,** and the animals the **fauna.**

Two constituents that enter into the composition of most soils are sand and clay. The former has large particles and therefore there are large air-spaces between them. This causes rain water to drain readily through the soil, but underground water will not easily rise by capillarity through it. Clay is the exact opposite. Thus a soil containing much sand is rather dry, but well-aerated. A clay soil, on the other hand, is liable to be water-logged. In some districts the soil contains a good deal of chalk, and this has its own characteristic flora of chalk-loving plants, *e.g.* **Deadly Nightshade** (*Atropa Belladonna*), **Wayfaring Tree** (*Viburnum*), **Spindle** (*Euonymus*). On the rather exposed chalk downs we find short turf and low growing plants, **Salad Burnet** (*Pote-*

Fig. 486. THE POPLAR. Twig and male catkin.

rium sanguisorba), **Rock Rose** (*Helianthemum*), **Thyme** (*Thymus serpyllum*), **Yellow-wort** (*Chlora*), **Rampion** (*Phyteuma*).

A soil must contain humus, that is decaying vegetation, in order to provide food for the plants. Humus, which is spongy, also helps to improve the water content.

Fig. 487. Blac

2. FLORA AND FAUNA OF PONDS AND STREAMS

Plants and animals that live in water and around the water's edge constitute very definite communities and have defined characteristics whereby they are adapted to li e in their watery home.

By ponds and streams we find the same trees growing, namely Poplars, Willows, and Alders. There are several different species of **Poplar.** The flowers grow in inflorescences called catkins (Fig. 486). Catkins resemble spikes, but the flowers have only stamens, that is, are staminate, or only pistils, in which case they are pistillate. A common species is the Black Poplar, *Populus nigra* (Fig. 487). The staminate Black Poplar tree is a lovely sight in early spring, when it is covered with dark-red catkins, while yet bare of any sign of leaf. The colour is due to the anthers, which, however, contain the usual yellow pollen. The pistillate tree is not quite so attractive early in the year, but has its interest

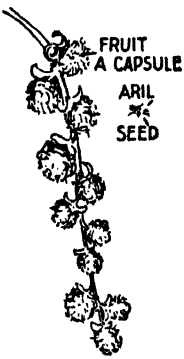


Fig. 488. Poplar Catkin.

later when the fluffy seeds (Fig. 488) are shed and the ground beneath the tree is strewn with what looks like cotton wool. The Black Poplar possibly received its name in contrast to the White Poplar (*Populus alba,*) which has a greyish trunk and in which the under surfaces of the leaves appear white owing to a covering of hairs. Aspen, *Populus tremula,* is similar to *P. nigra.*

All Poplar leaves have long petioles, flattened where they join the blade, and consequently they are always

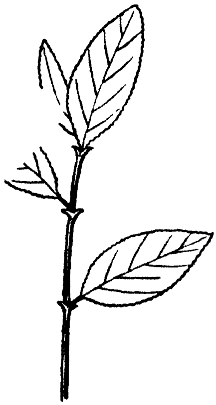


Fig. 489. SALLOW LEAVES.

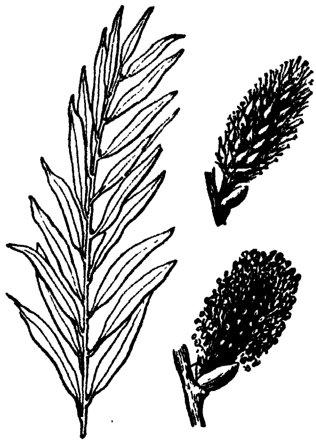


Fig. 490. THE WILLOW. With male (lower) and female (upper) catkins.

fluttering, even on a still day They seem to be holding a whispered conversation—" The poplar gentle and good." This is especially the case with Aspen Poplar, and hence has arisen the legend that the Cross of the Crucifixion was fashioned of Poplar wood, and the Aspen for ever sighs with grief.

Poplar wood is very soft, and hence the trees suffer from the goat moth larvae, which bore into them and eventually make a cocoon of wood chips.

There are also many species of **Willow** (*Salix*) to be found. The earliest flowering one is the Sallow, or Goat Willow, well known as Gold and Silver Palm. The plant is actually more bush-like than tree-like, and the catkins are erect, not pendulous. This is perhaps connected with the fact that they are insect-pollinated. The Sallow provides nectar in March, for the first bees that venture abroad after the winter sleep. The Silver Palm is from the pistillate tree and the Golden from the staminate. It has probably acquired the name Palm because it often makes decoration for Palm Sunday.

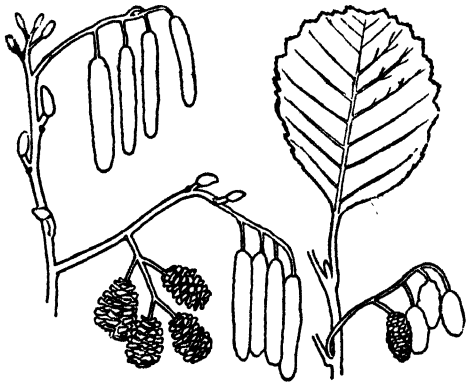


Fig. 491. ALDER.
The twig shown at the left bears male catkins, four young female catkins (above), four fruiting catkins (below), and five resting buds; the twig at the right (summer) has four fertilised catkins.

Sallow leaves are broad and short (Fig. 489), but there are other species with long, narrow leaves, such as the White Willow (Fig. 490). They are about the first trees of the year to show much leaf.

> " The willow is smart in a suit of yellow
> While brown the beech trees wait."

Willow branches are often cut back drastically, right to the trunk. This is called " pollarding," and it makes the tree grow long, tough shoots, osiers, used in basket-making.

The **Alder** (*Alnus*) is a stiff tree, but when pollarded it becomes bushy. Early in March before the leaves appear

(Fig. 491) it is covered with long, yellow staminate catkins. The pistillate catkins are much smaller, and are reddish and erect; later they form small woody cones, which may be found on the tree at all times of the year.

Growing along the banks of streams and round ponds are always a good many herbaceous plants, such as are able to grow with their roots in swampy ground. Early in the year the banks may display for us a golden buttercup yellow, due to the flowers of the **Kingcup** (*Caltha*) (Fig. 492), which is a relative of the Buttercup. Mixed with them may be found racemes of pale mauve flowers with a structure like the Wall-flower. The plant is about eight inches high, and has a pinnately compound leaf. It is called by various names, viz. **Lady's Smock, Milkmaid,** and **Cuckoo Flower** (*Cardamine pratense*).

Fig. 492. Caltha.

During the summer months there is a wealth of vegetation to be found. Near the very edge of the banks of rivers and ponds, probably right in the water, we find a plant with very large leaves and an inflorescence two or three feet tall, much branched, and bearing many small lavender-coloured flowers. This is the **Water Plantain** (*Alisma*). You would probably notice the extreme smoothness of the leaves of the whole plant, and this is a feature characteristic of many water-loving plants. This is perhaps because, in its wet situations, it

is not likely to be troubled with crawling insects, against which the hairs also protect it. The smoothness extends even to the flowers, which in many plants, also have hairs to prevent small insects crawling in and stealing the honey without pollinating the flower.

Other tall plants growing near the edge are **Rushes** and **Sedges.** Rushes with small greeny-brown flowers, have stems, and often leaves, which are cylindrical and glossy green in colour. The flowers grow in clusters, sometimes at a distance from the pointed tip of the stem. The plants have long, creeping rhizomes, which help to bind the marshy soil and give other plants a foothold in it.

Probably you are familiar with the pliability of rush stems and leaves. This is due to the large pith with its many air-spaces. It is also characteristic of these water-side plants to have many air-spaces or sometimes a hollow, air-filled pith. The pliability of rushes has made them useful in the making of mats, etc. Sedges are very similar to grasses, but may be distinguished by a triangular stem.

Amongst the Rushes and Sedges we sometimes see **Bur-reed** (*Sparganium*). It has long bayonet-shaped leaves and flowers in rounded heads, reminding us of Burdock.

In some favoured places in early June we are delighted by the tall, yellow **Iris,** and in autumn by its ripe fruits opening and displaying pale brown seeds. Tucked amongst these tall plants are patches of short ones. Everyone knows the bright-eyed **Forget-me-not** (*Myosotis*), but the water-side species is smooth, not hairy, like the one you have in your garden. Another little blue flower, sometimes mistaken at a distance for Forget-me-not, is **Brooklime** or **Water-speedwell** (*Veronica*); its flowers, however, do not grow in coiled cymes like Forget-me-not (Fig. 493), but in racemes (Fig. 494). The Brookline has only four blue petals and Forget-me-not has five.

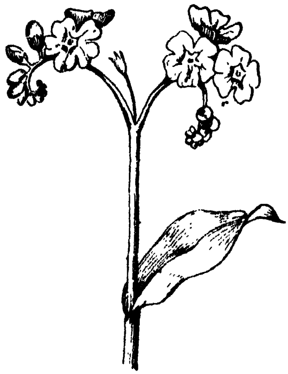


Fig. 493. INFLORESCENCE OF MYOSOTIS.
Scorpion-grass, Forget-me-not.

The Forget-me-not, however, has one near relative by the water, much taller than itself, namely **Comfrey** (*Symphytum*) (Fig. 495). The bell-like flowers are arranged in coiled cymes, like those of Forget-me-not flowers. They vary in colour from pale yellow to rich purple. In contrast to most water-side plants Comfrey is covered with stiff hairs. It flowers from April to August.

Two other low-growing plants are the familiar **Watercress** (*Nasturtium officinale*), which has racemes of white flowers like Wallflowers, and **Water-mint** (*Mentha hirsuta*). The latter has a square stem, opposite and decussate leaves, and heads of tiny, lilac flowers. It is very hairy, and when bruised a strong smell of peppermint, due to oil within the leaves, is produced.

We have not yet finished with the tall plants, which attract attention during the summer, by brightly coloured flowers. **Hemp Agrimony** (*Eupatorium*), with its reddish stems, appears in flower in July and August. The pale purple heads consist of tiny capitula. In warm weather Hemp Agrimony is swarming with red admiral, peacock and tortoise-shell butterflies, sipping its nectar.

Fig. 494. BROOKLIME VERONICA.

In July and August we also see the rosy flowers of the **Hairy Willow**

Herb (*Epilobium hirsuta*), so-called because its leaves resemble Willow leaves. In the autumn the plant's long, narrow fruits burst and allow tiny, hairy seeds, like shuttlecocks, to escape (Fig. 478). More attractive still is purple **Loosestrife** (*Lythrum*), with long handsome spikes of rose-purple flowers. This has flowers with a corolla-tube within which the stamens and stigma occur at three different levels.

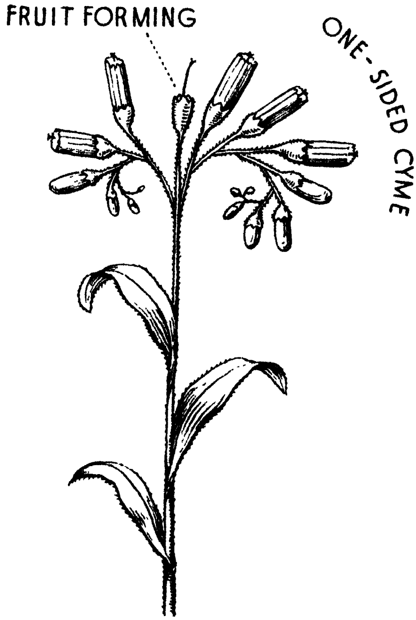


Fig. 495. COMFREY.

Living amongst these plants by the water are a number of mammals, all with bodies adapted for swimming. One quite often seen is the **water vole** (Fig. 496). Its smooth, glossy fur is reddish-brown, but tinged slightly grey above and much more so below. Although frequently called a rat it is obvious from our figure that it differs greatly from that animal. The ears are hard to see, because they are flat against the head; this is an advantage to a water animal. The animal lives in a burrow in the bank of the stream, and as it is a vegetarian, sometimes it may be seen feeding on plants near the water's edge. It is a rodent like the rabbit, and must therefore continually gnaw hard substances. In the early summer five or six babies are born in a nest of dry grass and other plants.

Another fairly common mammal is the **water shrew.** This animal has black and white fur and a sharply-pointed nose. Its body is only about three inches long, but its tail is another two inches. It feeds upon smaller water creatures of all kinds.

In addition to the life around the edge, there is abundance of it actually in the water. Already the simple plants, the algae, have been noticed. In addition to these there are many angiosperms.

Conditions of life in water are rather different from those

Fig. 496. The Water Vole.
Note the blunt snout, curved incisor teeth, depressed ears, thick neck, short legs and tail.

on land. In the case of some large plants all the plant's surface is bathed in the water, from which it will derive its water, mineral salts, and some or all of its oxygen and carbon dioxide. All the parts which are submerged will take part in absorbing water and substances dissolved in water. This work is therefore no longer confined to root-hairs—in fact, the latter are not produced. In addition, since the stem and leaves are able to absorb food for themselves, a complicated and well developed system of tubes for conveying food to these parts is no longer needed.

The development of wood is very small. It is because each organ thus absorbs water for itself and has no protection against losing it easily, that a water plant withers very quickly when brought into the air. There is more carbon dioxide dissolved in water than is present in air, but the amount of light, which reaches the plant through the water, is diminished, so that it can very easily obtain as much carbon dioxide as it can absorb energy to use.

The mechanical conditions are altogether altered. The plant no longer has to support itself against the atmospheric pressure in order to stand erect—the water will hold it up. There is such a large percentage of water in the plant that there is no struggle at all with the water from this point of view. We have seen that only a small amount of wood is needed for conduction of sap. Wood is a very efficient strengthening tissue, and this also is not needed to any extent. The small amount of wood is placed in the centre of the stem, as well as in the root, because the water has a pulling-force and the central position is the best for resisting it, as in the case of the root of the land plant.

Many water plants are not rooted at all, but float freely in the water, either at or beneath the surface, and in such cases the need for resistant material in the stem is still further reduced.

If the water is running water, leaves with large surfaces would be a hindrance, and therefore many plants have small leaves, or leaves which are cut up into a large number of small, fine pieces, which allow the water to flow between them easily. Being divided the leaves have a larger surface for absorption.

The one great difficulty a water plant has is breathing. The amount of oxygen dissolved in water is small, and consequently not so easy to obtain. To meet this difficulty the water-plant develops a large system of air spaces, in which air, having once entered the plant, is stored and not

allowed to escape too easily. These air-spaces can often be seen with the naked eye, if we cut across a piece of the submerged part (Fig. 212).

Water presents some difficulty with regard to pollination, and hence many water plants produce their flowers above the surface of the water, so that wind or insect pollination may occur. There are some cases, *e.g.* **Grasswrack** (*Zostera*), which are specially adapted for water pollination.

Fruits or seeds are usually dispersed by water so that they may reach suitable situations for germination and growth.

In studying water plants a sharp distinction can be drawn between those with leaves floating on the surface and those which are entirely below the surface, *i.e.* submerged. Perhaps the most familiar of floating leaves are those of the **Water-lily** (*Nymphaea*) with its large, nearly circular leaves and **Duckweed** (*Lemna*) (Fig. 497), which, although only a small free-floating plant, sometimes forms so thickly on the surface of a pond or ditch, that it gives it the appearance of being solid. In these cases the upper surface of the leaves is in contact with the atmosphere, and therefore adapted to use it, like a land plant. There are stomata, through which gaseous exchange goes on; and the epidermis is protected from giving off too much water vapour in transpiration. Duckweed has tiny, yellow flowers which arise actually on the apparent leaves. Since only stems can bear flowers these leaf-like structures must be stems; such a leaf-like stem is called a cladode.

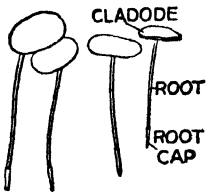


Fig. 497. Duckweed.

Water-lily leaves are very characteristic, being rolled up (so that they are like a ball) in the bud. The leaf stalk is attached very near the centre of the leaf (Fig. 498), although the margin is cut and the lamina is not an unbroken piece, as it is in the common Nasturtium. The upper surface

has a coating of wax, or bloom, to keep it dry. Thus the stomata are always free and unblocked, because any water which happens to get on the upper side, just rolls off like water from a duck's back. There are very large air-spaces in the leaf stalk, which is so adapted that the leaf will always float, although the level of the water rises and falls. The stem is a rhizome growing in the mud. The flowers, which are quite large and conspicuous, also float on the surface of the water, spreading out their petals in the sun-

Fig. 498. WATER-LILIES.

shine but closing them in the evening to protect the stamens and carpels.

A familiar plant, which has floating leaves in addition to submerged, is the **Water Buttercup** (*Ranunculus aquatilis*). Those which are submerged are finely divided, and those which come into the air are palmately net-veined, with the general adaptations the same as in the Water-lily (Fig. 499). The floating leaves in this case are specially produced towards the flowering period. At this time an increased supply of food is needed, and it is

important that the shoots bearing flowers keep near the surface of the water. The flowers resemble Buttercup, except that their petals are white; and they must be above the surface of the water in order to attract insects.

Some species of **Potamogeton,** common in rivers, also have oval, floating leaves borne on long stalks. The flowers of this plant are produced in spikes above the water; some having stamens only and some carpels. The pollen is carried by the wind.

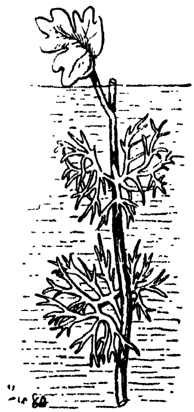


Fig. 499. RANUNCULUS AQUATILIS. Showing a floating leaf and two submerged leaves.

Plants which live below the surface may be rooted in the mud. Here a rhizome travels along in the mud and produces a group of ribbon-like leaves and adventitious roots at the nodes. **Water-violet** (*Hottonia*) also has a rhizome, which grows in the mud, but it produces long shoots, bearing very finely divided leaves (Fig. 500). The stems continue growing and produce, above the water, flowers which are lavender-coloured and like Primrose in structure.

Other plants, such as the **Canadian Water-weed** (*Elodea*), although submerged, float freely, not being rooted at all. Roots are produced, but not very plentifully, and they simply hang freely in the water. The stem branches very freely and bears numerous small leaves (Fig. 501).

Callitriche (**Starwort**) is an interesting little plant in that it shows the effect that life in the water has in altering a plant. It has small, oval leaves, arranged in pairs at right angles. Those at the top of the stem are very close because the internodes are so short (Fig. 502). They form a star which floats on the surface, and have the upper surfaces, where there are stomata, waxed to keep out water. Below

the surface the leaves are well separated because the light is dimmed by travelling through the water, and dim light causes the formation of long internodes. The submerged leaves are also much thinner and without wax, since they need to absorb not the gas carbon dioxide, but the pond water containing it in solution.

Fig. 500. WATER VIOLET.

Most water plants have some special method by which they spread in addition to the formation of seeds, which is somewhat difficult and therefore rather uncertain. In many cases the leafy stems become broken into pieces, which continue growth as new plants. Many of them have underground stems, which continue to grow year after year—that is, they are perennials.

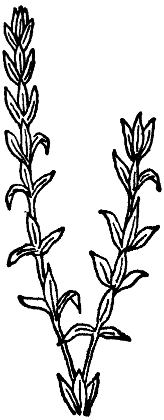


Fig. 501. ELODEA.

Those which float freely produce special buds in the autumn. *Elodea*, for instance, produces at the tips of the branches a cluster of leaves with very short internodes. In due time the rest of the plant begins to wither, and these buds drop off and sink to the bottom where, owing to their close formation, their weight is sufficient to cause them to sink a little into the mud. Here they are protected from the frost, snow, and much of the cold of winter. The temperature here never reaches freezing-point—in fact it does not get below 4° C., until the whole pond or river becomes a solid mass of ice.

In the spring, when the temperature rises and the light increases with the lengthening days, these buds begin to grow. As soon as the internodes lengthen a little, they come floating to the top of the water, where they are stimulated by the warm, bright sunshine to grow.

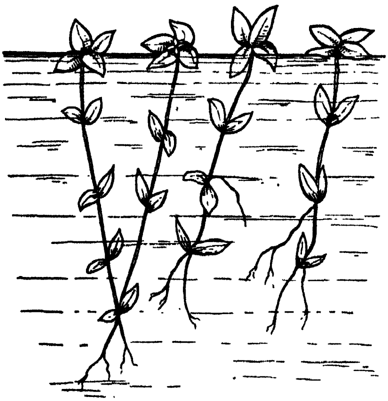


Fig. 502. CALLITRICHE.

Water teems with animal life, most of the big groups being represented in it. In a shallow, stony part of the pond may be found on the under side of smoother stones, blackish creeping creatures, like leeches, but thin. They are distinguishable from leeches by their method of locomotion—gliding instead of looping. Their movement is partly muscular, but is also helped by the cilia on the skin. They may also be found on the floating leaves of water plants in a stream, and live upon small water creatures. They are **flatworms,** *e.g. Planaria.* At the head of the animal a pair of eyes may be seen, and more usually numerous eyes fringe the head and even extend some distance along the sides of the body. The mouth occurs at the end of a protrusible pharynx, somewhat nearer the posterior end of the body than the middle (Fig. 503).

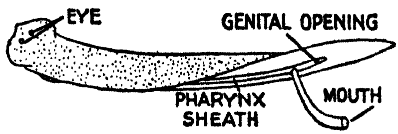


Fig. 503. A FLATWORM.

There is no spacious body-cavity and no blood vessels, but embedded in the reticulate mesoderm, in much the

same way as veins are embedded in the tissue of a leaf (instead of lying freely in a space as in other animals studied), is a much branched gut, and an equally branched system of excretory tubes. All the excretory products are collected into a duct, which runs along the middle of the body from near the anterior to an excretory pore at the posterior end.

There is also a very much branched reproductive system. The animal is hermaphrodite. The ovary is branched, both the testes are branched, and there is a system of very numerous, narrow tubes in which yolk for the eggs is formed. There is an opening near the pharyngeal opening on the ventral side—the genital pore—from which the eggs escape. Thus the solid substance of this thin creature is perforated by an elaborate system of tubes serving various purposes. Simple it is, but it shows bilateral symmetry and has distinct posterior and anterior ends, and in the anterior region are two groups of nerve cells, which give off nerve fibres, so that here is the beginning of a brain.

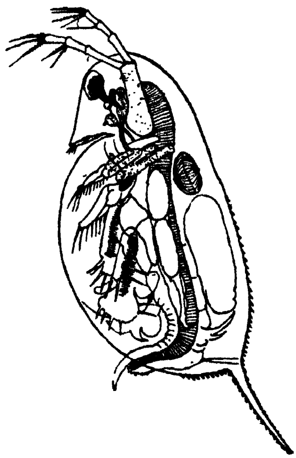


Fig. 504. DAPHNIA.
A common water-flea.

Planaria exhibits to an amazing degree the phenomenon of regeneration; almost any part, if severed from the rest of the body, will reproduce parts necessary for a complete animal.

Daphnia is known popularly as the water-flea. A jar full of pond water or water from a stream can scarcely fail to contain some of these creatures. It is very, very small, only about 2 mm. long, but can be clearly seen with a lens (Fig. 504).

These tiny beings belong with the crayfish to the Crustacea, and the term flea is therefore misapplied, because fleas are really insects. With them lives yet another crustacean, namely the **fresh-water shrimp** (*Gammarus pulex*). The body of Daphnia is not very distinctly segmented, but it is seen to bear several appendages (Fig. 504), and the body is protected by a shell. The antennules are very small, but the antennae are well developed and adapted for swimming. The other head appendages that daphnia possesses are mandibles, first maxillae, and second maxillae. It has also six pairs of thoracic limbs, all used in swimming. The abdomen is much reduced, turned forward, and ends in a telson. There is a large brood chamber between the shell and the back of the female, and in this many broods are hatched during the summer.

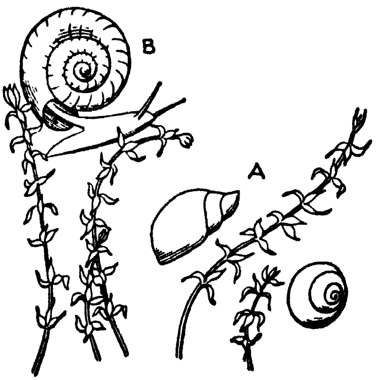


Fig. 505.
A, Pond snail; B, Trumpet shell snail.

The phylum Mollusca is represented by the **fresh-water mussel**, already described. This, having a bivalve shell and plate-like gills, is a lamellibranch. Water snails provide examples of the gastropod class. There are two kinds of **water snail**, one, e.g. *Limnea*, with a sharply-pointed shell and one with a flat trumpet shell (*Planorbis*) (Fig. 505). These creatures are vegetarians and very useful in aquaria since they clean the glass by browsing upon the green plants which readily cover it. The water snails have only one pair of tentacles instead of

two as in the case of land snails. Snails lay from twelve to sixty eggs in oval clusters. Each egg is surrounded by jelly, and the egg clusters are called snail spawn. They may be found on the backs of floating leaves, or often, in aquaria, on the glass.

There are many **insects** which pass the larval stage in water, although the imago may spend its life on land. On the surface of any fairly shallow water on a spring or summer day may be seen the larvae and pupae of gnats, already described.

Much larger than the gnat larvae and in lesser numbers are **dragon-fly larvae.** Some live at the bottom of the pond or shallow part of the stream; other small species live amongst the foliage of aquatic plants, near the surface. They can be kept in an aquarium. There are different families of dragon flies, and consequently larvae differing in appearance, but all are alike in being a dirty brown colour to match the bottom of the pond. Some have wide, strong bodies, and others are thin and delicate looking. Of the larger sorts, some like to be half-buried in the mud, and consequently are covered always with material from this source.

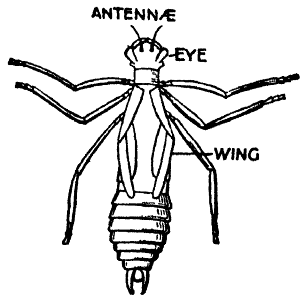


Fig. 506. Dragon Fly Larva.

A dragon fly larva (Fig. 506) has a large head, very large, dull looking eyes, and small antennae. On the thorax are six long legs, and when the larva has moulted a few times two pairs of small wings. With each moult these wings grow larger. The abdomen is segmented and has at the end three large and two smaller spines, or, in the case of the larvae of smaller species, three leaf-like outgrowths. These are for respiration, as they are furnished with tracheal tubes,

and function as branchiae. Around the rectum is a network of tracheae, and these extract oxygen from water entering the rectum from the posterior end of the body. If the water in the tank containing the larvae gets foul, they will be seen with these spines projecting above the surface in order to obtain oxygen from the air. The larva has spiracles, and can therefore breathe out of water.

Dragon fly larvae must be supplied with meaty food in the shape of other insect larvae, tadpoles, and small fish. Hidden beneath the head is a part called the mask. It is really part of the labium and bears two teeth, which close over the mouth and hide it. When food appears this mask is shot out and the teeth behave like pincers. It is carried to the mouth, where mandibles and maxillae cut it into pieces.

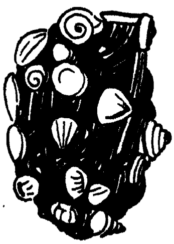


Fig. 507. Caddis Case.

The larger larvae take more than one year to complete their development. It is a gradual process, there being no definite larval and pupal stage. When it is time for the imago to emerge the larva may often be seen with head and thorax above water. Eventually it climbs up the bank or up the stem of a water plant, its skin splits, and with great labour the dragon fly pulls itself out.

The **caddis fly** has indeed a unique larva, popularly called caddis worm. They may be found wherever vegetable food is available, looking like bunches of rubbish, for the larva is hidden inside a case cleverly made of pieces of plant stem, small shells, grains of sand, or stones, fastened together very firmly by some sticky material (Fig. 507). The material of the case depends upon the species of caddis fly. Species found in a pond build their homes of pieces of plant or of shells, which may be used even when inhabited. In streams, where the water is running, sand or small stones are used and pieces of vegetable matter attached.

Where the water is swift the cases are attached to large stones, which will not easily be moved.

Ordinarily, nothing but the head and thorax of the larva project from its case, and it cannot be pulled out, for there are at the posterior end of the body, hooks by which it holds firmly to its home. If a pin be inserted in the back of the case the larva will hastily leave it. This done, if it is a pond species, it will either return or build a new case in a remarkably short time.

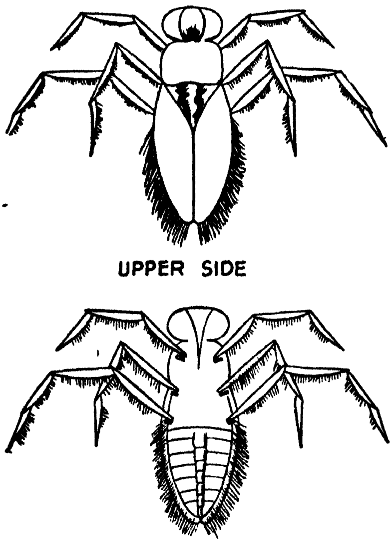


Fig. 508. WATER BOATMEN.

The larva is very similar to a caterpillar, except for the three pairs of long legs on the thorax. It lives on vegetable food in much the same way as a caterpillar. The head bears on the under-side a silk gland, from which comes the material for sticking the case together. Along each side of the abdomen are tufts of fine threads which are the tracheae. The larval stage lasts about twelve months. If you find a case with a grating across the door you will know that the larva within is becoming a pupa. At the end of this stage it tears the grating, climbs into the air, like the dragon fly nymph, and the fly (which resembles a small brown moth) emerges.

Water boatmen (Fig. 508) swim on their backs, using their back legs as a boatman uses his oars. The larvae resemble

the adult, except in possessing no wings. Even the adult spends its life in water. It is carnivorous, devouring young tadpoles and other water creatures. It habitually rests near the surface and catches any water midges.

Among the vertebrate animals, the amphibians are represented by **tadpoles** of the frog, toad, and newt.

Toad spawn occurs in strings (Fig. 509), instead of in large masses like frog spawn; and newt's eggs are laid singly and fastened up in the leaves of water weeds. The adult newts (Fig. 510) spend a good deal of time in the

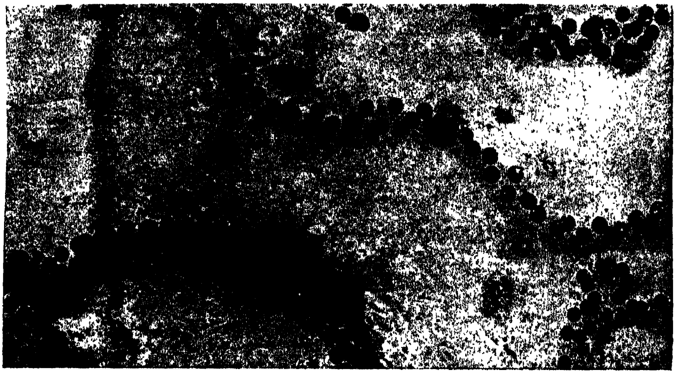


Fig. 509. Spawn of Toad.

water during the early part of the year, when they breed, and are never found far from water. In contrast to frogs and toads, they retain the long tail of the tadpole. There are two common kinds, crested newts with a crest on the back, and smooth newts in which this is absent. Both are browny-grey above, but yellow with dark spots below.

Then there is the vertebrate class Pisces, of which all the members, namely the fishes, are adapted for life in water. There are a large number of freshwater fish (Fig. 112), but as they are more easily able to live in running water we find greater variety in the streams than in ponds.

We think at once of **ducks** and **swans** as inhabiting ponds and streams. These have webbed feet for swimming (Fig. 511). They feed upon water plants and small water creatures, and both build nests among the rushes and reeds. A swan's nest is large and contains six or seven green eggs. The fluffy, grey baby birds are called cygnets.

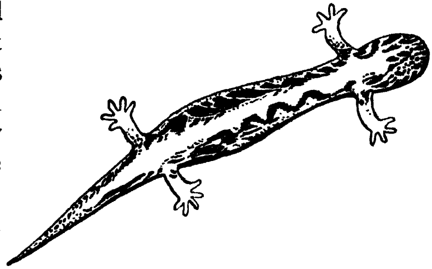


Fig. 510. Newt.

Another bird to be seen swimming across a pond or stream is the **moorhen.** This bird is dark olive brown in colour, but has a bright red forehead. The feet are not webbed, and the nest, made of dry rushes and reeds, is built off the ground in a

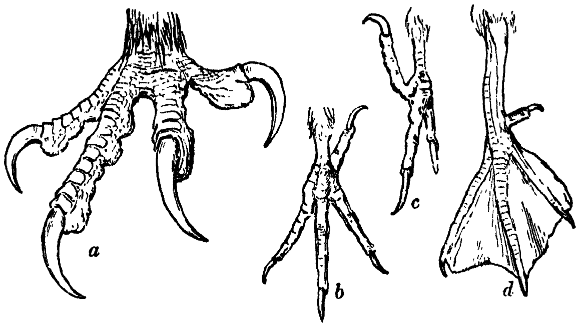


Fig. 511. The Feet of Birds.
a, Eagle; b, Pigeon; c, Woodpecker; d, Duck.

tree stump or low bush, and contains eight to twelve large, reddish-white eggs blotched with brown. The fluffy chicks can swim immediately they are hatched. The **coot** is larger than the moorhen, and is distinguished by its white forehead.

Anywhere near water we usually have the fortune to see the **pied wagtail.** He is about the size of a sparrow, but has a long tail and slender body. The feathers are black and white and the tail is moved rapidly up and down. It is delightful to see it walking over Water-lily leaves. This is one of the birds that really only comes to the water to drink and for the sake of the abundant insect life there. Many other birds which really inhabit hedgerows and woods will come to a pond or stream to drink and bath.

By the stream we may see the brown **sedge warbler,** which builds a grassy nest, cleverly fastened to the stalks of tall rushes. The **kingfisher,** with his gorgeous coloured plumage, reminds us of tropical birds rather than of our own sombre-coloured feathered natives. The bird has a short, stumpy tail and long, thin, sharp beak. He sits quietly by the stream and then suddenly darts to the water, capturing fish with his powerful beak. These are swallowed whole, and later the bones regurgitated. The nests are made of fish bones at the ends of tunnels in the river bank. If possible the bird uses a tunnel already made by some fellow creature, such as the water vole. The eggs are pure white.

Another fisher is the grey-plumed **heron.** He stands by the water on long stilt-like legs, with shoulders high and eyes half closed, and when occasion offers, gnats, a fish, or frog, or even a water vole meet with an untimely end. This bird's nest is built of sticks in the tree tops.

A water habitat is easier to produce artificially on a small scale than any other, namely in the shape of an aquarium. The bottom should contain a layer of soil with sand on top to prevent the soil from making the water muddy. A few clean stones to provide shelter for animals should be placed on the bottom. Into this soil layer plants can be tucked. Lead foil, which can be buried, is useful to weight them and thus keep them down. Those without

roots can be put together in small bunches and the ends pushed into the soil. Plants which will not grow too large must be chosen, e.g. *Elodea, Myriophyllum, Callitriche, Ceratophyllum, Vallisneria.* Duckweed forms a useful screen on the surface of the water. The aquarium must be kept in a bright, but not sunny, place where the plants will give off plenty of oxygen thus keeping the water fit for animals to breathe in. When the plants are settled animals can be introduced. Fish are a difficulty unless the aquarium is rather large and the water is flowing in and out of it. In still water they soon use the oxygen, and they are so active they need a large space in which to move. Newts can be kept, but should have a stone poking out of the water, so that they can come out and rest on it.

Perhaps the easiest and most instructive things to keep are insects, boatmen, dragon fly larvae, caddis larvae, water beetles. It is also easy to obtain frog spawn and newts' eggs, and watch the development of the tadpoles. It must be remembered that these creatures cannot be put all together in a small aquarium, for in those circumstances the smaller, weaker animals quickly become prey for the larger carnivorous creatures. Snails are very useful in an aquarium as they are vegetarians, and in crawling over the glass lick off the small green algae that grow on it and make it cloudy. Snails can be safely put with any creatures except the large water beetles, *e.g. Dyticus*, and so also can caddis larvae since they are protected by their case. Dragon fly larvae and newts will attack tadpoles and water boatmen, and the latter, when large, are likely to destroy tadpoles. All but the vegetarians must be fed. Large dragon fly larvae and beetles may be fed on earthworms, but will take raw meat, which should be put in on wire or cotton and withdrawn when they have sucked the nutriment from it. Smaller dragon fly larvae and boatmen will feed on *Daphnia* and similar small creatures which can be kept in a tank apart, where they

will multiply, and can be put in at intervals. Newts can be fed with small earthworms.

3. FLORA AND FAUNA OF HEATHS AND MOORS

This habitat contrasts with the preceding one, in which the plants found abundant water and food, and therefore produced luxuriant vegetative growth on which animals could feed. Heaths and moors are characterised by being vast stretches of land which is comparatively flat although often high, and exposed to scorching sun and drying wind. This exposure has a marked influence upon the soil, particularly as it is usually of a sandy nature. The surface layers are usually very dry, the moisture quickly draining through, and the sun and wind causing rapid evaporation. As a result of this, decomposition is very slow, conditions being too dry during most of the time for bacteria and fungi to do their work. Thus not only is the amount of food relatively scarce, but many of the intermediate products of decomposition are of an acid nature, which makes osmosis difficult.

Plants growing in these positions, therefore, find the absorption of food difficult: further, neither water nor food are plentiful. In the aerial parts, atmospheric conditions are very favourable for transpiration. Both these factors make the supply of water a problem, consequently we find adaptations for absorption and also for the reduction of transpiration, so that the water may be economised. The water problem and the not too plentiful supply of food would tend to keep the plants small. Trees are absent, or stunted Silver Birches and Mountain Ash sometimes occur. The bushes, Furze and Broom, have strong, wiry stems to resist the wind, and the other plants are low-growing.

The roots of heath plants are long, so that they may penetrate to water in the lower layers of the soil. In order to obtain an adequate amount of food many heath

plants enter into partnership with small, simple plants. The roots of **Heather** (*Calluna*) and **Heaths** (*Erica*) do not bear root hairs in the normal way, but are clothed with a mass of fine threads, the hyphae of a fungus which have entered the surface layer of cells of the root. The hyphae grow very long and cover a much larger area of soil than would root hairs. They are able to absorb carbohydrates and proteins, which exist even though decomposition has not occurred. This fungus is called a mycorhiza. The roots of **Broom** (*Genista*) and **Furze** (*Ulex*) bear nodules containing nitrogen-fixing bacteria, which make amide from gaseous nitrogen. In all these cases the partnership is an example of two organisms living together for mutual benefit, that is symbiosis. The fungi and bacteria are provided with a sheltered home and receive carbo-hydrate manufactured by the green plant.

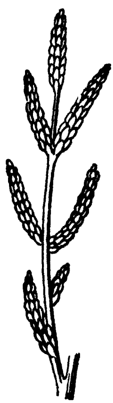


Fig. 512. Heather or Ling.

In order to reduce transpiration the plants have small leaves, *e.g.* Heather (Fig. 512), Heaths (Fig. 513), and Broom (Fig. 514). They may be somewhat rolled, with the stomata inside and hairs on the surface with the stomata. In this way a damp atmosphere is maintained around the stomata. Heather, the Heaths, and Furze are evergreen. Broom and **Bilberry** (Fig. 515) shed their leaves, but are nevertheless evergreen since they have green stems, and in this Furze resembles them. In this way these plants are able to manufacture carbohydrate food even during the winter.

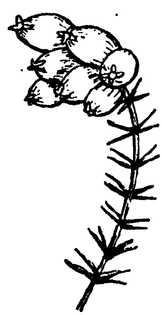


Fig. 513. Cross-Leaved Heath.

In Furze the branches are reduced to spines (Fig. 516). The stems are furrowed and the stomata sunken in the furrows to

protect them from excessive transpiration. Young Furze seedlings are spineless and have compound leaves with three leaflets; but as the plant grows the need to reduce transpiration causes simple leaves and spines to develop. The seedling form may be retained by growing it where the roots can receive a plentiful supply of water and the atmosphere is kept rather damp, under a bell-jar, for instance.

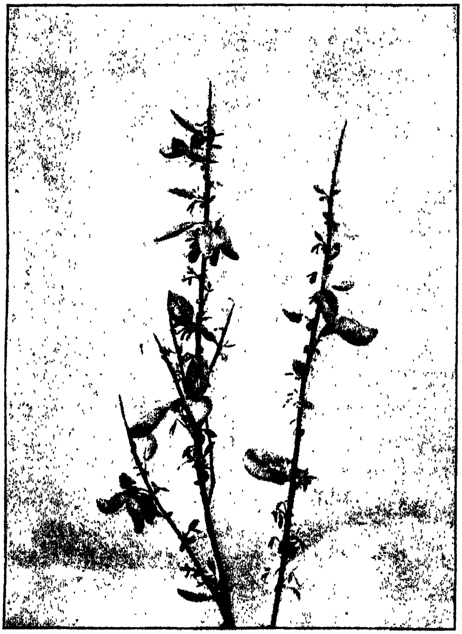


Fig. 514. THE BROOM PLANT.

Furze bushes and Heather sometimes may be seen looking as though they have been covered with pink cotton. On investigation the cotton is found to be the twining stem of a plant. The stem bears only very small, pinkish scale leaves until it develops groups of flower buds which open out into very pale pink, bell-shaped flowers. This peculiar plant is **Dodder** (*Cuscuta*). It has no chlorophyll and no connection with the soil and cannot therefore obtain the materials to manufacture its own food. It obtains the necessary carbohydrates and proteins from the Furze or Heather plant by means of projections, called suckers, which can be seen in groups on the stem, and

look rather like caterpillar's feet (Fig. 517). These suckers make a connection with the wood and bast of the plant on which Dodder is growing. Dodder does no honest work for itself, and is called a **parasite**, while the unlucky plant on which it grows is the **host.** It is an annual, shedding its seeds in early autumn. The seed germinates in the soil, sending down a small root which absorbs water. The stem grows up as a long, thin thread, waving its tip round to catch a plant stem on which it can hold. Should it not find one, it will wither and die of starvation. If it finds a stem round which it can twine, it catches hold of it and then sends into it suckers.

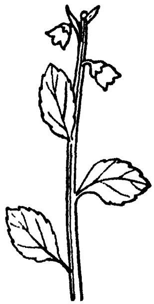


Fig. 515. BILBERRY.

Dodder also chooses for its host other plants besides Furze and Heather, *e.g.* Hop, Flax and Clover. It is a relative of Bindweed (*Convolvulus*), which is a green plant seeking support by means of a twining stem. Dodder has, as it were, degenerated into the lazy and somewhat risky life of parasitism. If a field of Flax, for example, is infested with

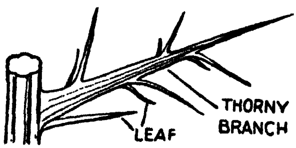


Fig. 516. FURZE OR GORSE.

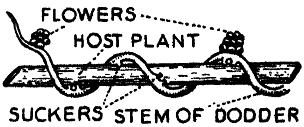


Fig. 517. DODDER.

Dodder, the parasite is bound to appear next year if allowed to shed its seeds and again provided with a suitable host plant.

Another parasitic plant is the **Broomrape** (*Orobanche*). The common species, *O. major*, grows on Furze and Broom. It is only noticeable during the flowering period as all the purely vegetative part is underground. The inflorescence

Fig. 518. BROOMRAPE (*Orobanche*).

is a spike, and each flower is in the axil of a large, rather fleshy bract (Fig. 518). At first the colour of the whole is rather yellow, but later becomes a purplish-brown. There is no suggestion of green. The underground part consists of a rather swollen rhizome completely covered with fleshy, scale leaves. The rhizome bears adventitious roots, which fasten themselves to the roots of the host plant. There are other less common species of *Orobanche*, which grow on other hosts.

The vegetation of heaths and moors does not provide very appetising meals or much shelter for animals. Reptiles are represented by **snakes** and **lizards.**

Certain parts of the moorlands are liable to be very wet owing to the presence of a thick layer of peat, that is, undecomposed organic matter. These parts, known as the **bogs,** are colonised chiefly by the **Bog Moss** (*Sphagnum*). This is of greyish-green colour, and may be

tinged with pink. The upper part is very much branched, making a thick tufted layer at the surface of the bog. The branches grow so dense and are themselves so sponge-like (a large part of them being composed of water storage tissue), that they often efficiently keep the water from spreading over the neighbouring land.

Accompanying the Bog Moss are **Butterwort** (*Pinguicula*) and **Sundew** (*Drosera*), which overcome the difficulty of obtaining food by the insectivorous habit. Sundew has been described in Chapter XXVIII. *Pinguicula* has a rosette of yellowish-green leaves (Fig. 519), which have rather a slimy and dotted upper surface, and the edge is slightly rolled upwards. The appearance of the surface suggests food to insects, and small kinds, such as flies and midges, crawl over the leaf, possibly getting some satisfaction. Those which crawl, or get washed, to the edge, are hindered from getting away by the fold, and over their bodies is spread a digestive juice which kills them and dissolves a good deal of nitrogenous food, already in the form of proteins, from them.

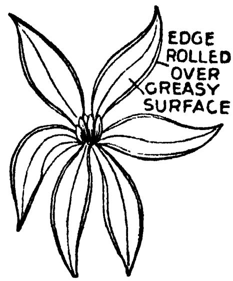
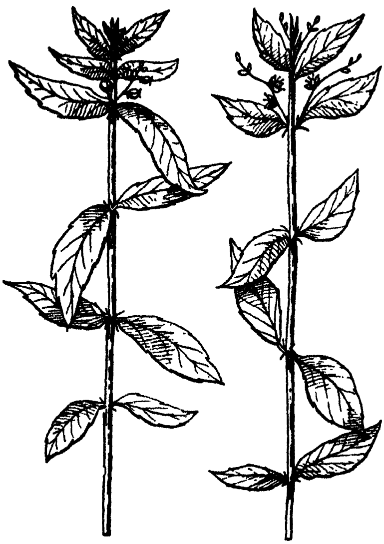


Fig. 519. BUTTERWORT.

4. WOODLANDS

A wood is a unique situation and a wonderful co-operative society, the dominant feature being the trees. These are large and tall, and catch a large share of the sun and rain; nevertheless there is some undergrowth. There are young trees of the same kind as the large, also shrubs and some small herbaceous plants, as well as ferns. The herbaceous plants mostly flower early in the year before the foliage of the trees has emerged from the buds, and supply a beautiful spring carpet. They provide themselves with

underground food storage organs in order that they may begin growing early while the temperature is still rather low. Ferns with their very large leaves and slow habits of growth (each leaf takes a year to develop in the bud and another year to unfold) are adapted to a shady situation.



PISTILLATE PLANT STAMINATE PLANT

Fig. 520. Dog's Mercury (*Mercurialis*).

Just as there are layers of vegetation above ground, so there are layers in the soil. The roots of the large trees penetrate much farther than any others, the shrubs have an intermediate layer, then come the ferns, and lastly the herbaceous plants. In this way each root system has its share of the soil and does not interfere with either the larger or smaller plants.

A wood usually consists mainly of one kind of tree. The kind of tree depends on the soil and the tree influences the undergrowth. If the soil is chalky we find **Beech woods.**

The leaves of Beech trees form such a perfect mosaic that a Beech wood is more shady than any other. Smaller trees occur only on the edges of the wood, and in the ground flora one plant occurs to the exclusion of all others. When this is the case the one plant is said to be dominant. The dominant plant in this case is **Dog's Mercury** (*Mercurialis*).

It has probably received the name " Mercury " because it grows so rapidly. The leaves are opposite and decussate with toothed edge (Fig. 520). They are very thin so that what light there is penetrates to the chlorophyll. In common with all woodland plants the leaves become very large after the flowers are over. This increases the surface for photosynthesis when the shady time comes. Dog's mercury is dioecious, that is, has male and female flowers on separate plants, both flowers being small and green. The inconspicuousness of the flowers suggests wind pollination. The staminate flower has three perianth leaves and a good many stamens on long filaments, and the pistillate has a two-carpelled ovary.

In the better lighted parts of the wood, near the edge or where the trees are thinner, **Dog Violets** (*Viola canina*) occur (Fig. 521). These have no scent, and are rather paler in colour than the sweet-scented violets. They overcome the difficulty of possibly being overlooked, and so not pollinated, by producing later in the season flower buds which never open. These are called cleistogamous flowers. The word means " hidden marriage," and the pollen grains in the anthers grow out pollen tubes which enter the ovules. The shrubs which occur near the edge are **Hawthorn** (*Crataegus*), **Wayfaring Tree** (*Viburnum*), and **Dogwood** (*Cornus*).

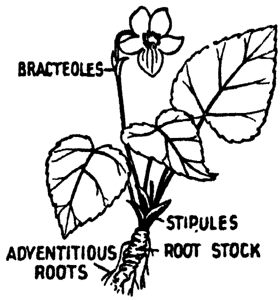


Fig. 521. Dog Violet.

Dry Oak woods occur on slightly high ground, where the soil is well drained and possibly sandy and therefore not damp. The dominant tree here is the **Sessile Oak** (*Quercus sessiliflora*). Oak trees cast less shade than beech and therefore more plants are able to grow beneath them. A dry oak wood provides us with an excellent example

of the ground flora having their roots at different levels in the soil. The three dominant plants are **Soft Grass** (*Holcus lanatus*), **Bracken Fern,** and **Bluebells** (*Scilla nutans*), see Fig. 522.

Bluebell seeds germinate and form tiny bulbs on the surface layers, but in their second and third year they develop contractile roots, and by the time they are large enough to flower they have been pulled right down to their proper level in the soil. The reserve food in a Bluebell bulb assists it to flower early, and pollinating insects are attracted by the strong scent as well as by the colour.

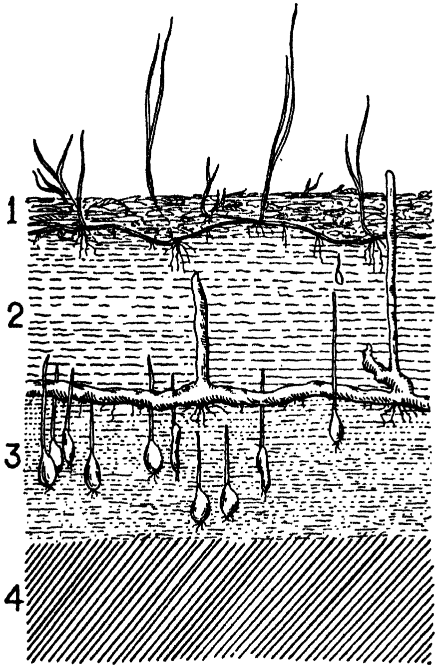


Fig. 522. SECTION OF SOIL.
Showing how Yorkshire Fog Grass, Bracken, and Bluebell live together, their underground parts being at different depths.

The commonest shrub in this wood is **Holly.**

Damp Oak woods are formed where the soil holds water. Here the dominant tree is **Pedunculate Oak** (*Quercus pedunculata*); and partly because of the dampness we find a varied ground flora. Some of the plants already mentioned occur, and in the same way some of those found in a damp oak wood occur in other woods, but are never dominant.

Fig. 523. The Lesser Celandine.

Fig. 524. The Wood Anemone.

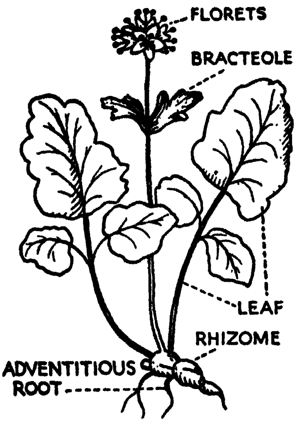


Fig. 525. Adoxa.

In this type of wood we find **Primroses** (*Primula veris*). Earlier than the primrose comes a little star-like yellow flower with structure resembling a Buttercup. In fact it is a species of the Buttercup genus, commonly known as **Lesser Celandine** (*Ranunculus ficaria*). It has smooth, shiny leaves (Fig. 523). Another early flower is **Wood Anemone** (*Anemone nemorosa*), a beautifully graceful little blossom often called "Wind Flower" (Fig. 524). The three large leafy structures below the flower are really bracteoles. The foliage leaves, which are similar in appearance to the bracteoles, do not appear until the flowers are over. *Adoxa*, or **Moschatel,** is a plant with similar large bracteoles. The flowers are greenish, and it has a fleshy white rhizome (Fig. 525).

Another plant with very delicate white flowers is **Wood Sorrel** (*Oxalis*). It has leaves like Clover, but when evening comes they droop instead of folding (Fig. 526). The flowers are trumpet-shaped and often escape being pollinated, but this difficulty is overcome by having cleistogamous flowers.

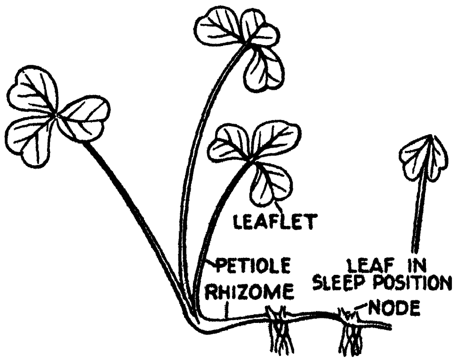


Fig. 526. Oxalis or Wood Sorrel.

All these plants have underground organs for food storage. Primrose, Anemone and Oxalis have underground stems, the two last in the form of rhizomes, while that of Primrose is short and vertical. Lesser Celandine has tuberous roots (Fig. 527).

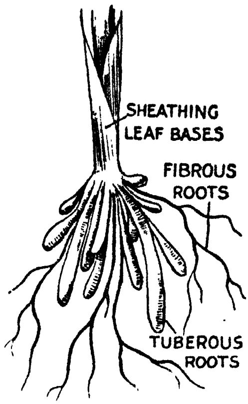


Fig. 527. Lesser Celandine.

A little later, **Wild Strawberry** (*Fragraria*) (Fig. 344) may be found spreading by means of runners and with it *Lysimachia nemorum*, a plant with reddish, creeping stem, rounded opposite leaves and small yellow flowers (Fig. 528). *Lysimachia nemorum* is known as **Yellow Loosestrife**, or Yellow Pimpernel, because it so closely resembles the Scarlet Pimpernel.

Quite a number of shrubs and bushes occur in a damp oak wood. **Hazel** (*Corylus*) is usually dominant, but with it are **Hawthorn, Sloe, Dogwood**, and **Willow**. The undergrowth becomes very dense as the branches of one Hazel frequently touch those of the next, "The Hazels hold up their arms for arches, when Spring rides through the wood." The wood also shelters climbers, namely **Rose** (*Rosa*), **Blackberry** (*Rubus*) and **Honeysuckle** (*Lonicera*). The last flowers somewhat late

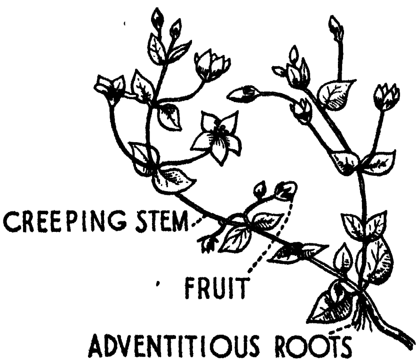


Fig. 528. Wood Loosestrife or Yellow Pimpernel. (*Lysimachia nemorum.*)

in the year, but attracts to it night-flying moths for pollination by virtue of its pale colour and strong scent at night.

Pine trees are evergreen, and their needle-shaped leaves prevent too much transpiration during the winter, since they have no flat surface to become really warm. The leaves have a flat side; the flat sides of a pair face one another, and here most of the stomata occur so that there is a damper atmosphere between the two leaves and immediately next to the stomata.

As the trees are evergreen, the wood is always shady, and nothing is found growing in it but **Toadstools.** Since Toadstools feed upon decaying vegetation, they are plentiful in any wood, receiving a rich food supply from the fallen leaves. In the more open parts of a pine wood, Silver Birch trees may occur. Where there is enough light for ground flora characteristic moorland plants occur, such as Heather, Furze, Broom.

We cannot think of a wood without its abundant bird life. Birds which are rarely seen out of a wood are the green and the lesser spotted **woodpecker.** The former is the larger and more handsome bird. Its body is bright green and yellow, and the top of the head scarlet. The other species is black and white with some red colouring.

These birds are quite unique in using their strong beaks to make holes in the trees in which to build their nests. Their flight is somewhat awkward, but they can run nimbly up a tree trunk. The feet are adapted for this purpose, having two toes directed backward and two forward (Fig. 511). The bird feeds largely upon insects, and it is possibly in searching for them that it makes a tapping noise with its beak on the tree trunks. To assist it in getting the insects from cracks in the bark, it has a long tongue.

In a wood, too, we find the **wood pigeon** or **ring dove.** Its plumage is slatey-grey with green, blue, and purple on

the head, neck, and breast. When in flight white bars may be seen on the wing and white patches on the sides of the head. It builds high in the trees, a nest of sticks and twigs in which are laid two round white eggs (Fig. 392).

The soft " coo " which we sometimes hear is the note of the **turtledove,** which is with us only during summer. This bird is smaller and brownish in colour.

The large **kestrel** and **sparrowhawk** both nest in woods, often just repairing and enlarging the nest of some other bird. They are called birds of prey because they live upon other animals—mice, rats, frogs, slugs, beetles—and even upon small birds and their eggs. For the purpose of tearing the flesh of their prey, they have beaks with the upper jaw hooked and overlapping the lower and also sharp curved claws (Fig. 511). In the open they may be seen ready to pounce upon the animals which their sharp sight enables them to see from great distances.

Much smaller denizens of the wood are our beautiful **tits.** They are familiar to us because during the winter, when food is scarce, these little insect eaters venture near our houses in the hope that we will put out lumps of fat for them. The two common tits are the **blue tit** and the **great tit**; their colouring is similar, viz. olive-green backs, bluish wings and tail, yellow breasts, blue heads, and white cheeks, but the great tit's head is a very dark blue. The great tit is, as its name implies, larger. The blue tit can be distinguished by having on each side of the eye a line of blue feathers across the white cheek. Great tit has earned the name sawfinch on account of the sawing noise it makes. Both birds choose a hole in a tree in which to build their nest, which is made of moss and lined with hair or feathers. The eggs are creamy white with red blotches, especially at the wide end. Often a large number, twelve or more, are laid. It has been suggested that the whiteness of the eggs enables them to be seen easily in the somewhat dark hole in the tree, and this is true also of

the round, white eggs of the **tawny owl,** which are laid in a hole in a tree but with no carefully built nest.

Everyone associates the **nightingale,** little brown bird with the wondrous song, with a wood.

A well-loved mammal of the wood is the **squirrel.** The true British squirrel is reddish-brown in colour; the grey variety was brought from America. Squirrels make nests of moss, roots, and grass in the trees, and here three or four baby squirrels are born about midsummer. Hazel nuts, beech nuts, mushrooms, haws, and even birds and eggs form part of its diet.

During autumn they are busy collecting and storing food. It does not hide its store all in one place, but has several storehouses. When the cold weather really comes it curls up, wrapping its tail round its body, and hibernates. But it does not always sleep the winter through like a dormouse. If the day is warm it may wake, partake of some of its food store, and sleep again. The forgotten and unneeded fruits of a squirrel's winter store will often germinate, having been thus carried from their parent plant to a new home by the busy little animal.

Sometimes we may see a **fox** in a wood, since here it hunts for food.

A wood teems with **insect life.** It is a happy hunting ground for moth collectors during the evening. Often there are ant hills, and many different beetles. A beetle which often attracts attention because of its large size is the stag beetle, of which the male has a pair of large horn-like mandibles.

5. FLORA AND FAUNA OF A HEDGE

A hedge has several parts, which different plants find suitable for their needs. There are, of course, the actual bushes planted to make the hedge. These are usually planted on a bank with a ditch below.

The bank and ditch encourage the growth of plants which enjoy plenty of moisture and can overcome the

difficulties encountered in the shade cast by the hedge. Then extending out from the hedge is a grassy strip, where the ground is rather hard and dry, and which is exposed to the sun's heat.

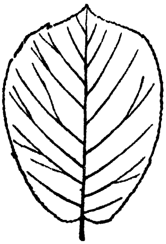


Fig. 529.
HAZEL LEAF.

Hazel (*Corylus avellana*) trees are often planted to form hedges because suckers arise from the underground parts—especially when the branches are cut back—and thick growth is made. The leaves are characterised by being wide at the top; the apex is pointed (Fig. 529).

In late January and early February Hazel trees bear long, pendulous, yellow staminate catkins and pistillate catkins like leaf buds except that they have a tuft of red hairs, stigmas, poking out at the top (Fig. 530).

Hawthorn (*Crataegus*) is another popular hedge plant. Hawthorn leaves have deeply cut edges and large leafy stipules (Fig. 531). In their axils are stiff thorns, which from their position must be modified branches. The pinky-white blossom comes in May. The structure of one of the fruits, known as haws, is shown in Fig. 532. They provide birds with much needed winter food, and in this way the seeds are dispersed.

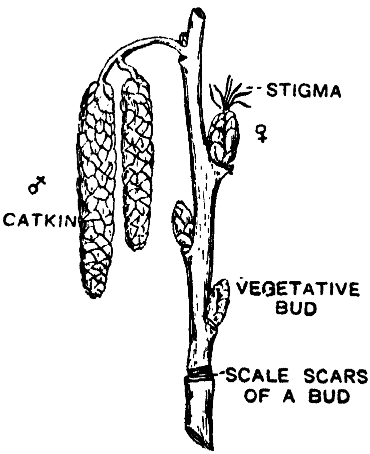


Fig. 530. HAZEL.
Male and female inflorescences.

Occurring less frequently and often scattered at intervals in the other hedges are **Blackthorn (Prunus)** (Fig. 533).

Field Maple (*Acer*), **Dogwood** and other bushes. Blackthorn provides a wealth of white colour against its black thorny branches, blossoming before it leafs. In late summer it has blue fruits like very small plums, which are called sloes. Maple has leaves and fruits resembling Sycamore.

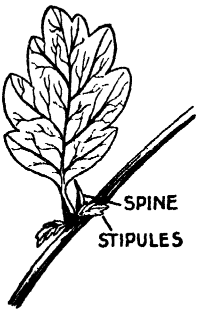


Fig. 531.
HAWTHORN LEAF.

Some plants, which start life in the partial shade of the more or less permanent plants of the hedge, grow very rapidly, having long thin stems, with long internodes. They thus make their way between the lower layers of vegetation, which they use to hold themselves up, for they have economised in strengthening tissue in their effort to reach the light as quickly as possible. Such plants are known as **climbing plants**, since they attach themselves to other plants or suitable objects which will serve to support them. Some of these have been described in Chapter XXVIII.

Rose and Blackberry are examples of climbing plants, which, having pushed their way amongst supporting material, hang on by means of spines. These are outgrowths of the epidermis, occurring on the stems, leafstalks, and often on the midribs, and are curved in order to hold on firmly (Fig. 534). The rose flower is well known with its urn-shaped receptacle, delicate pink petals, and numerous orange stamens. The fruit is the hip.

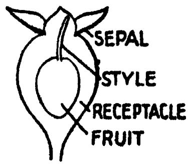


Fig. 532.
HAWTHORN.
A False Fruit.

The climbing habit enables a plant to reach the sunshine and fresh air, and to obtain a good position for pollination and for seed dispersal with very little expenditure on strengthening material. They scramble quite quickly to

the top of the hedge, where the wind will have greater play in connection with fruit dispersal—as in Clematis (Fig. 376). Here also the insects see them more easily to seek their nectar and pollinate them, and the birds find their fruits to scatter the seeds (*e.g.* the Rose).

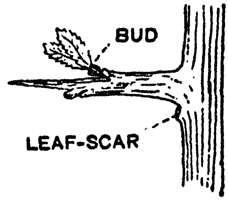


Fig. 533. SPINE OR THORN OF THE SLOE.

Luxuriant and varied growth is to be found on the **bank** beneath the hedge. It is clothed with long grasses, and amongst these we find Ferns, sweet-scented Violets, Dog Violets, Primroses, Bluebells, Barren Strawberry, Wild Arum, Speedwell, Dead-nettle, Hedge Woundwort, Fox-glove, Cow Parsnip, Jack-by-the-hedge, Stitchwort, Dock, and Stinging-nettle.

Some of these plants are to be found in a wood, where similar conditions of shade prevail. The species of grass are the same. These woodland plants in a hedge flower early just as they do in a wood, so many of them are to be found during April. The sweet-scented violets come earlier than the dog.

Fig. 534. PRICKLES OF ROSE.
S, Stipule.

Amongst short meadow grass by the **wayside**, we find **rosette plants** pulled down tightly into the earth by a contractile root stock, so that the growing point at the tip is safely out of harm's way (Fig. 352). Amongst plants of this description are Dandelion, Daisy, Plantain. The Thistle, too, begins life with a rosette of leaves, but later develops a stem bearing leaves and inflorescences. Growing with these we find Groundsel, Shepherd's Purse, Clover, and many others.

Dandelion, Daisy, Thistle, and Groundsel all resemble one another in having capitula of tiny florets as described in Chapter XX. Daisy closely resembles Sunflower. The others all possess fluffy fruits just as Dandelion does. Plantain bears spikes of small brown flowers, of which the staminate have stamens with long protruding filaments. They are wind-pollinated.

You have only to watch for a short time to realise that a hedge abounds with small **animal life**, usually destructive to some of the foliage. **Snails** and the woolly bear **caterpillars** of the tiger moth have a partiality for dock leaves. If there are stinging-nettles these may have caterpillars of the beautiful, small tortoise-shell butterfly. Caterpillars of the green-veined butterfly feed on jack-by-the-hedge; and those of orange-tip butterfly on hedge mustard; and there are also many others.

If it is warm enough butterflies are abroad, flitting from flower to flower, and then search can be made on the leaves for eggs which can be kept to become caterpillars: having found them on a leaf, this indicates their food plant.

Evidence of the existence of other types of insect may be seen in the **galls** found on the various plants, including the attractive, mossy, red rose-gall. These are caused by an insect piercing the plant and laying her eggs inside. These hatch into larvae, which remain inside the gall until they become imagos. The irritation caused by the bud being pierced, and by the larvae penetrating into the plant tissues, gives rise to these peculiar growths called galls.

In a hedge, when the darkness comes on, the tiny lamps of **glow-worms** may be seen. If one is found and examined, it will be seen to possess insect characters, but if it glows it will be the wingless female. The male is winged. It belongs to the class of insects known as beetles. They are active only at night and feed on snails. The lamp is just a luminous spot on the abdomen. The larva develops by slow stages into an adult, taking more than one year to do so.

The hedge also shelters a number of mammals. Perhaps the smallest is the long-tailed reddish-brown **field mouse.** This is similar to the species that is detested in our homes, Wherever mice are to be found **weasels** will not be far distant. The slim body of the weasel is about eight inches long. It is reddish on the back and white beneath. The narrow head, with rather small ears, ends in a sharp snout. It moves with great rapidity, and birds and birds' eggs fall a prey to it, as well as mice.

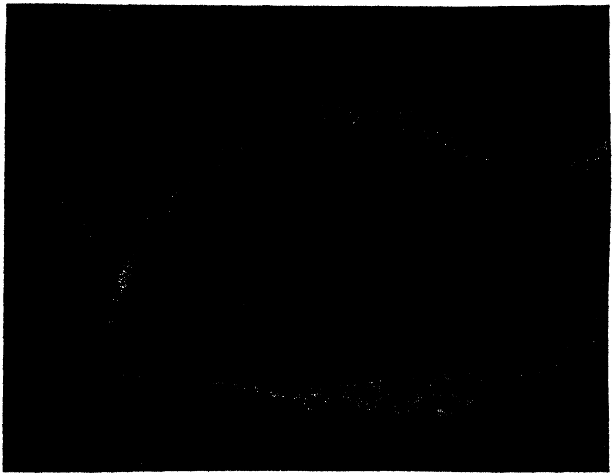


Fig. 535. THE HEDGEHOG.

Another four-footed animal attracted to the hedge because it will find food there is the **hedgehog** (Fig. 535), which feeds upon eggs, young birds, insects, frogs, snails, slugs, and worms. The name hedgehog is merited by the pig-like face, and it seems to sniff about after its food just like a pig. The food is sought by night, and during the day the hedgehog is usually found rolled up into a ball, well protected by its covering of long, sharp spines, which very efficiently prevent the animal from being interfered

with by others. Early in the summer the hedgehog searches for a hedge-bottom plentifully supplied with dead leaves wherein it may make a nest for its young. There are from two to four at a birth. At first the young are blind and their spines soft, but they are soon able to fend for themselves. During the winter the hedgehog again resorts to a nest of dead leaves, wherein it sleeps during the troublesome time of coldness and lack of food.

Fig. 536. HIBERNATING DORMOUSE.

The **dormouse** is also to be found in a hedge, where it can find Hazel nuts to feed upon. When the time comes to hibernate it makes a nest of dry grass in the bushes, sometimes using an old bird's nest, in which to put the grass. It sleeps curled in a round ball, with its tail wrapped over its nose and round its back (Fig. 536).

Many **birds** find in a hedge a suitable site for nesting, *e.g.* thrush, blackbird, chaffinch, linnet, robin, hedge-sparrow.

CHAPTER XXXII

HEREDITY, VARIATION, ADAPTATION, AND EVOLUTION

1. HEREDITY

Among the biological sciences the study of heredity occupies a prominent position, and in no region of knowledge is research more likely to increase man's power over nature. The breeding of plants and animals has a very wide-spread appeal. There is the peculiar charm of the young life and also the anxious enquiry and anticipation of the exact characters of the new generation. There is a wonderful fascination in the thought:

> " Like begets like
> Yet no two beings on this earthly ball
> Are like each other all in all."

Heredity is the transmission from generation to generation of characters which distinguish one kind of animal or plant from another, and also of individual peculiarities. A gentleman who happened to have six toes instead of the usual five, found it was a peculiarity shared by some of his ancestors and his children, and it therefore served as a useful factor in building up his genealogical tree.

The word evolution, literally means the act of unrolling or unfolding. It is applied to the gradual series of changes, by means of which the higher forms of life have arisen from the lower, and in fact by which the entire present-day conditions of the Universe have arisen from those of the past. The study of heredity has helped us to discover some points about the inter-relationship of species, and thence some possibilities with regard to how nearly related things may have arisen from a common ancestor.

At the beginning of the nineteenth century Lamarck, from a large number of observations, put forward the theory that organs became increased and developed through use, and similarly disuse is followed by dwindling and loss of power to act. He suggested that modifications thus resulting are carried on from one generation to the next, that is to say, they are inherited. The form of snakes is said to be due to their endeavours to creep through narrow passages, which were probably made in search of food, to get out of the direct sun, and to escape from their enemies. A giraffe's long neck may have been produced by their habit of browsing on trees; in competition with other animals which were also vegetarians, the giraffe acquired the habit of standing on tip-toe and stretching its neck to reach the tasty pieces above its fellows' heads. This habit constantly renewed and amplified by heredity may have given rise to the long-legged, long-necked creature of the present day from an ancestor which had very moderate proportions of both legs and neck. Differences which result from habits or changed environmental conditions, are known as **acquired characters.**

In plants, so far as we know, there is no voluntary striving after characters which would be advantageous. The stress and strain of environmental influences are, however, active agents in producing adaptations for specific purposes. Every flower with brightly coloured, attractive petals is adapted to provide food for an insect or bird, by which it is also adapted to be pollinated. In the same way insects are specially constructed to be able to take advantage of the flowers at their disposal. The story that the rocks have to tell us in their record of the past, very plainly and unmistakably shows that flowers and insects have evolved side by side. Before the flowers came there were no insects, and as the flowers specialised to need insects with longer tongues, so there were developed not only bees, but also butterflies and moths. At the

present time, as new orchids are being produced, so new moths appear which are able to remove the honey from them and pollinate them.

2. THE WORK OF CHARLES DARWIN

In 1859, the *Origin of Species* by Charles Darwin was published. This was a pioneer work of great value, because it not only contained the results of twenty years' patient and careful work of a master mind, but it also set free the thoughts of men into channels where they had not previously dared to stray. Its worth is obvious from the fact that it still lives to-day, as an ever-inspiring source of controversy, and therefore as a foundation stone of new and increasingly wider research and information concerning the relationship between the child and its parents. He came to the conclusion that small variations in the structural characters of plants and animals was a factor in evolution. In the Arctic regions the animals are white; whilst similar creatures, for example, bears, in warmer climates, where they live amongst vegetation of the wooded type, are brown. It must also be remembered that conditions may change and certain characteristics may consequently disappear. Thus in Holland and Belgium, the Willows assume a very storm-swept appearance, which is lost by the offspring if planted in a more sheltered situation. Caterpillars are usually quite difficult to find because of their similarity in colour to the material which is their food and upon which they therefore are normally found.

Darwin watched the struggle for existence by all sorts of living things that came into the world. The difficulty of obtaining food and sufficient space wherein to dwell is always present. Life from beginning to end is wrestling with the environment, first the inanimate and then the living, both friend and foe. The two-fold, never ending business of living creatures is to care for themselves and to care for

others. An existence having been maintained the question of progeny is the next consideration. This ever-increasing number adds to the **struggle for existence,** but it does and must go on. It is interesting to notice that in man, where the relative production of offspring is very small, the number of individuals is doubled in the course of twenty-five years. **Natural selection,** according to Darwin is the agent by which individual characters are maintained efficiently in succeeding generations, because in the struggle for existence the relatively fit tend to survive. Those which have characters helping them in their struggle will have advantages over their fellows, and thus tend to develop and produce offspring. It follows that in course of time if the same conditions prevail those with advantageous characters will show an increase in numbers while others will decline.

3. ABUNDANCE AND INTERDEPENDENCE IN NATURE

Although we may be entirely unaware of their existence, a bucket-full of water taken from the sea may contain more small plants and animals than we can count stars in the sky. All young fish as well as many large creatures, including one of our largest, the whalebone whale, feed on microscopic forms of life, and here we have the reason for the tremendous lavishness of Nature. Everything must have food, and everything in its turn provides food for something else. Living things must have food and space, and they all desire to produce offspring, so that in every walk of life, both great and small, plant, animal and human, there is perpetual over-crowding. Every plant and animal has to strive to get food, and it must also strive not to fall a victim to something else and be eaten itself, so that all through its life this dual striving must be maintained efficiently.

The sea has been called the cradle of life. Here, may be, life arose, and here we still find many very simple forms

and many very old forms, and here, as we have seen, on every hand we find extraordinary lavishness of Nature with regard to offspring. To give perhaps a more unexpected example, a British starfish, Luidia, lays 200,000,000 eggs a year. The oyster, with its fame as a delicacy and a home for the precious pearl, has sufficient great, great grandchildren for their shells, if they all grew up, to form a mass eight times the size of the earth.

Stepping on dry land we find the same story. There are many British plants of the Daisy group which produce more than one crop of flowers, and therefore seeds, each year. The familiar Groundsel, which is so pleasing to canaries, is one of these. The seeds produced are so numerous that it has been estimated that if they all matured, germinated, and the plants grew up and produced more seed without any hindrances, the progeny from one such plant would more than cover all the land in the world in three years.

The possibility of the production and survival of a vast number of offspring of a particular kind to the detriment of other forms is evidenced to-day at La Plata, where hundreds of square miles of land are covered with two or three species of European Thistle, almost to the exclusion of everything else. They arrived there accidentally; their one-seeded fluffy fruits so admirably adapted for dispersal by the wind and carriage to all sorts of places probably blew them on board some vessel amongst other goods, and thus, as stowaways, they made their passage across and then escaped and found a new home, which proved exceedingly congenial for them. The soil was good, the climate good, they met very few difficulties and grew apace. They were strange and therefore not eaten so readily as the familiar things in case they were harmful; they had left their diseases behind in the Old World, so there is no wonder they have gone ahead and occupy the land to-day so extensively.

The world of life can be compared to a spider's web. Everything, both great and small, strong and weak, conspicuous and inconspicuous, has a place in the great scheme of life, just as every tiny thread as well as the larger supporting thread, has its place in the spider's web. Nothing is too small or insignificant to matter. All are part of the one great whole, which at every turn is being moulded and welded together. It may be modified from time to time, but it will remain a harmonious and complete unit.

One may perhaps be surprised to learn that there is any connection between the loaf of bread on the breakfast table and the wriggling earthworm. Yet the loaf has been made with flour obtained from the ripened grain of wheat, which grew upon the wheat plant. In order that the wheat plant might develop to the flowering and fruiting stage, it needed warmth, air and sunlight to its stem, foliage and flowers, and in addition water, soluble salts and air in the soil for its roots. The circulation of air in the soil is maintained to a large extent by earthworms. These, therefore, become a factor in the production of the familiar loaf.

Every one, to some extent, is attracted by flowers. They have a tremendous value to the human race on account of their beauty and the pleasure they give. This attractiveness is no accident, it is one of the main features connected with their existence. They are, however, aiming at insects. The beauty of the petals, the colours, perfume, and shape are to attract bees, moths, butterflies, or other insects as desired, to a meal already prepared. The insect can only be fed if it follows its directions carefully and properly. It is required to become dusted on some part of its body with the pollen which emerges from the anthers of the stamens as soon as they are ripe. Having had a portion of its meal it is required to carry off this pollen to another flower of the same kind; and whilst it sips the nectar from this flower, the pollen is just in the right

position on its body to be rubbed on to the stigma of this flower. Only after this has taken place can the seeds be formed which provide the stimulus for fruit formation. Different flowers are adapted to different insects, and these in their turn are attracted by specific colours and scents, so that flowers and insects fit together like a glove fits the hand. Where and when the insects do not come seeds are not produced, and if in any season there were no flowers the insects would be short of food.

There have been many instances of this interdependence on an economic scale. Fig trees were taken from their home in the Mediterranean districts to California. Here the climate and soil were ideal for the Fig trees, and they grew apace. The foliage was beautiful and the trees grew to be some of the finest in the world, but the Figs were very disappointing, they were in fact quite useless. They were small, dry, hard and unpalatable, and continued so for about a hundred years. During that time science solved the riddle. A small wasp enters the case of the fig, lays her eggs in some of the specially designed seed-boxes, and whilst doing so deposits pollen on the stigmas of others. She can neither enter nor leave without rubbing through a mass of stamens. This is quite necessary if the fig is to swell and become soft, juicy, and edible. The introduction of this wasp to California having proved a success, rapidly brought fame to the Californian Fig, which it could never have had alone.

Taking particular instances one can follow up a chain of events, such as the connection between the familiar domestic cat and the Clover crop used either for fodder or ploughing in as a green manure. The Clover flower is specially adapted to bees, and more particularly humble bees. The Clover head is a large collection of small flowers clustered closely together. In each of these tiny flowers the stamens and the carpel together with the nectar are hidden in closed petals, which need a heavy

insect to open them. In the Clover there is a wonderful contrivance to help the insect so that time and energy be not wasted. Each little flower which has received its due share of pollen and had its nectar removed, assumes a drooping, instead of erect position, and thus the bee knows it is too late, it has been forestalled. The number of seeds produced by the clover crop depends upon the number of bees in the district. The nests of the humble bee are very much interfered with by field mice, consequently the number of bees depends upon the number of mice, and these in their turn depend upon the number of cats sufficiently near to disturb their peace. In this way the number of seeds obtained from the Clover crop depends upon the number of cats which are cherished as pets by the neighbouring inhabitants.

As we look more and more closely at Nature, so we find every niche of opportunity is filled, every nook and cranny, every hole and corner seems to have been found and colonised by some form of life seeking a spot where it may dwell.

As we have seen, bacteria multiply at a tremendous rate, and this rapid rate of breeding is characteristic of small forms of life generally. Many unicellular animals multiply so that there would be several millions of them in a week. To consider a larger form, the aphis, or green fly, so destructive, as all lovers of gardens and vegetation know, to the young, tender shoots in spring, increases so rapidly that these shoots must be carefully watched if they are to be preserved, a single day of neglect may mean their destruction. One female aphis produces young at the rate of one per hour for several days, so that a very moderate few soon becomes a numberless host. In fact if they all survived and continued to have a plentiful supply of food and keep up this rate of breeding, in one year the aphid population would be sufficient to weigh down the human population of China.

The value of small animals of the past which lived, multiplied, and died, is evidenced by the existence of coral reefs and chalk cliffs. These have been piled up inch by inch by the accumulation of their bodies, chiefly in the one direction, for a considerable period of time. Just as—

> " Little drops of water, little grains of sand,
> Make the mighty ocean and the glorious land."

so the minute coral polyp has built the coral reef, year by year, new individuals growing and building their castles on top of the forsaken homes of their forefathers.

4. HYBRIDISATION

In the year 1900 the work of Gregor Mendel was rediscovered, and it gave an entirely new trend of thought and a new set of ideas upon which to work. This work was rediscovered and put before the world by De Vries, Correns, and Tschermak. It had remained hidden because this man, a contemporary of Charles Darwin and a Roman Catholic monk who became the Abbot of Brünn, did his work in the very great seclusion of the monastery walls.

Mendel's work was experimental and carried out through several generations, being mainly botanical, and begun in connection with the common edible Garden Pea. To him an organism became a very complex assemblage of " unit characters," or **allelomorphs**, each of which could be independently inherited and also combined in a variety of ways, even in the offspring from the same two parents. In his experiments he selected certain characters such as the form of the ripe seed, which might be smooth or wrinkled, the colour of the seed leaves or cotyledons which he noticed was sometimes green and sometimes yellow. The two characteristics, relating to the same part, thus making an allelomorphic pair, were artificially united by cross-pollination, and the result in the offspring

anxiously awaited. It was found in these cases that the next generation resembled one of the parents, and the other character had disappeared. The seeds resulting from crossing those with yellow cotyledons with those that had green cotyledons were all yellow in the hybrid generation. Yellow was therefore called the **dominant** character of the pair, and green, which had become hidden, the **recessive.** That the recessive character was merely latent was shown by allowing the hybrid plants to develop and produce flowers, and by self-pollination fruit and seed; care being taken that no foreign pollen was admitted. The result was that both yellow and green ones were produced, in the proportion of three yellow to one green. This can be briefly indicated thus:—

Yellow Green

Yellow

Yellow Yellow Yellow Green

Later Mendel used two characters together, smooth, round seeds which had green cotyledons, and seeds in which the testas became wrinkled whilst they were ripening, and the cotyledons yellow. The hybrid exhibited the two dominant characters, namely the smooth coats and yellow cotyledons. These plants were allowed to continue and self-fertilise as before, with the result that four kinds of offspring resulted. Some resembling the hybrid, some each parent, and a few had wrinkled coats and green cotyledons. It was found that nine resembled the hybrid, three were like one parent, and three like the other, and one was the new combination. Thus, taking two pairs of characters, Mendel produced two new forms, the hybrid and one in sixteen of the next generation.

Thus was established a method of obtaining a new variety. Further, it is a method which in the first place cannot fail, and in the second, cannot help perpetuating itself if it survives in the struggle for existence. The first generation consists entirely of the hybrid, which is continued in the next generation in the proportion of nine out of sixteen. The second hybrid does not appear until the next generation and then only in a rather small proportion, but it has the advantage of breeding true when once it has appeared. It contains the two recessive characters only, and no others; therefore it is hiding no secret, it is wrinkled and green, and so will all its progeny be until some additional character is introduced from elsewhere. This can be summarised briefly thus:—

```
            WY    RG
              \  /
               RY
                |
   ------------------------------------
   |          |          |            |
  9 RY       3 WY       3 RG         1 WG
```

Further experiments established that the three to one hypothesis obtained by using one pair of characters, really resolved into one dominant, two hybrids, and one recessive. For instance, in the case of the yellow and green cotyledons, the yellow being the dominant and the green recessive, of the three yellow, one would breed true, having a double share of the yellow character. This is said to be a **homozygote.** The other two had the yellow character and the green which was hidden from view, and are therefore **heterozygotes,** and these two on further inbreeding would each behave like the first hybrid and give offspring in the proportion of three yellow to one green. The recessive one is homozygous, having a double share of the recessive character and would breed true.

This may be briefly represented thus:—

YY GG

Y(G)

YY Y(G) Y(G) GG

or to make it more general, the initial letters of terms dominant and recessive may be used to represent the characters, thus:—

DD RR

D(R)

DD D(R) D(R) RR

DD RR

DD D(R) D(R) RR DD D(R) D(R) RR

It is interesting that this agrees with the mathematical Law of Probability. If a large number of black counters be shaken up in a bag with an equal number of white ones, and then they are removed in pairs, they will come out in the proportion of one pair of black, one pair of white, and two where one is black and one white.

The resolution of the three to one hypothesis was helped by the fact that the hybrid did not always resemble a parent, but contained a blend of the characters which might give an entirely different appearance. A classical example is seen in the Andalusian fowl which is blue and cannot be made to breed true. Here the blue fowl is undoubtedly new. When bred on, the progeny are in the proportion one like each parent and two blue. When once the information has been ascertained as to the origin of

this hybrid, it is no longer a chance production, but its repetition is quite reliable. This type of variation is sudden and abrupt, there are no gradual stages leading up to it. It is called a **mutation.** There is no environmental reason why a mutation should appear, it is just the chance meeting of the necessary units of character in the sexual cells, or else their intentional mixing by the breeder or experimenter.

In 1880 the Rev. Wilks of Shirley found a poppy with a narrow white border to the petals, instead of the usual red with just a dark spot near the centre of the wild poppy. This mutation was regarded as a freak or sport, but as it was attractive, as well as interesting, it was kept under observation and the progeny observed. From this chance hybrid, which also accidentally attracted attention, have since been developed the tremendous and fascinating varieties of the Shirley Poppy which has become a favourite garden flower.

Factors are sometimes more complicated than they appear at first. Thus grey rabbits mated with white ones gave rise to rabbits which were grey, but spotted with purple. In the next generation there were nine like this hybrid, to three grey and four white. Further breeding showed that of the four white, three possessed the purple spot factor, but this could not show in the absence of the grey coat. The white colour or albinism is brought about by the absence of colour, or often some other factor which prevents the colour from showing.

Reversion is brought about by the accidental meeting again of factors belonging to distinct, though complementary, allelomorphic pairs. Thus the mating of two albinos frequently produces coloured offspring.

During the present century a great deal of work has been done in connection with the question of heredity. It has been applied economically in connection with plants and animals, so that really good suitable strains may be

bred. Some work has also been done in connection with disease. It has been shown by hybridisation that immunity from disease is a character which can be conferred upon varieties of Wheat and transmitted to their offspring. On these lines some very valuable strains of Wheat, Potatoes, and other crops have been produced. There seems no question that heredity plays an important part in directing the present and shaping the future. J. Arthur Thomson suggested that heredity, function, and environment are the three sides of the biological prism by which we seek to analyse the light of life, but there may be other components.

The complete potential nature of new types as well as old is already laid down in the germ cells previous to fertilisation. Mendel's discovery enables us to form some mental picture of the process which results in genetic variation. It is simply the segregation of a new kind of gamete bearing one or more characters distinct from those of the type.

The characters which are handed on from one generation to another are believed to reside in the chromosomes of the nucleus. Each chromosome is composed of a number of **ids**, each of which in its turn carries certain factors or **genes.** It has been noticed earlier that, when reduction division or meiosis occurs, four new units are made, not simply two. This phenomenon is definitely associated with sexual reproduction and therefore, sooner or later, with gamete production. The cells so made are really two pairs from the point of view of the characters they possess; or it is possible they should be regarded as four distinct strains. An individual or unit factor, is either present or absent. Thus the yellow Peas have a factor which causes the chlorophyll to change during the ripening of the seed; and when this factor is absent the seeds remain green.

Similarly it has been determined that the shape of the cotyledons is due to the presence or absence of a factor

which completes the conversion of sugar to starch during ripening. This is present in the round Peas and absent in the wrinkled. If one pair of allelomorphs, *e.g.* yellowness and greenness in Peas is considered, the parents being pure strains, or homozygous, their gametes are YY and GG respectively. The heterozygote of the next generation is YG, and its gametes are all either Y or G, which will occur in equal numbers. This being true of both male and female gametes there are four possible combinations. So that if four squares are made to represent the female gametes thus:—

Y	G
Y	G

and four others to represent the male gametes, thus:—

Y	Y
G	G

If then these squares are superimposed to represent the mating, the following zygotes are obtained:—

YY	GY
YG	GG

which are one homozygous yellow, two heterozygous yellow, and one homozygous green, or absence of the factor needed to produce yellow.

When two allelomorphic pairs are concerned, such as yellowness and the absence of yellowness, together with roundness and the absence of roundness, there are four possible combinations in both the male and female gametes. They may contain the two dominant characters, either may be absent, both may be absent. Representing these two characters by Y and R respectively, and their absence by y and r, the hybrid would be $YRyr$. Since this hybrid is heterozygous for the pair Yy, it will give in the next generation $YY + 2Yy + yy$. This is denoted by the four large squares in the diagram. Since it is also heterozygous for Rr, this pair will appear in the next generation in the proportion $RR + 2\ Rr + rr$. This is represented in the diagram by dividing up each of the original squares into four again.

YY RR	YY R*r*	Y*y* RR	Y*y* R*r*
YY *r*R	YY *rr*	Y*y* *r*R	Y*y* *rr*
*y*Y RR	*y*Y R*r*	*yy* RR	*yy* R*r*
*y*Y *r*R	*y*Y *rr*	*yy* R*r*	*yy* *rr*

Of the sixteen squares resulting, nine contain Y and R, three contain Y but not R, three contain R but not Y, and one has neither. Further it may be noticed that only four of these sixteen zygotes are homozygous for both of the unit characters. These are represented by the four squares on the diagonal starting at the top left-hand corner.

As the number of allelomorphs concerned increased, so the number of forms in the second generation also increases,

but in a perfectly definite and orderly way, giving quite distinct combinations of these factors in definite proportions to one another.

5. CONCLUSION

The present is the child of the past and parent of the future. Some record of its past history frequently appears in the embryo and early life of the organism. Thus the vertebrate animals, which live on land, have at some period of their embryo life gill slits, showing that they have had a relationship with fishes in the past. In the Bracken Fern we saw how the stages of evolution of the stele were gone through in its early life. Those same types of stele, representing the stepping-stones to a dictyostele, are the adult type present in some Ferns still, as well as in others belonging to past ages. Gorse (*Ulex europea*), seedlings always have small, soft, trifoliate, stipulate leaves at first, before their ability to become modified to spines, to suit the dry, exposed situation on a heath or moor, becomes apparent.

Evolution has brought order out of chaos. It means more than the unfolding of those things which already exist, as happens when a bud unfolds and the stem and leaves appear. It includes the incessant appearance of new qualities, new characters, new powers, new beauties. By means of evolution we see the possibility of change as well as continuity. The existence of life involves change, and new forms are necessary to carry on under the altered conditions.

Variation is a fact of life. New forms must and do arise, and if the new characters are useful and profitable under existing conditions they will be kept and maintained by the great sieve natural selection. Such changes as are unprofitable at the time will gradually, or perhaps suddenly, disappear. Thus the scene is always changing, slowly but persistently changing, not only in the past, but to-day, before our eyes.

APPENDIX

1. PRESERVATION OF MATERIAL

Plant material that is to be used for sectionising should be preserved in methylated spirit for a time. This not only allows it to be kept for any length of time desired, but it also hardens it, so that it is much easier to cut. It is therefore wise to treat all material such as stems, roots and leaves in this way. Leaves may become too brittle. This is easily remedied by placing them in water for fifteen to thirty minutes before use.

Small plants, such as Chlamydomonas, Spirogyra, Mucor, it is essential to examine fresh.

Animals can be preserved in 5 per cent. formalin. A dissection should be started with a freshly killed animal, but it can be kept as long as desired in formalin. Parts may be preserved as specimens for future examination either in formalin or methylated spirit. Owing to the presence of chitin, if it is desired to preserve insects the following fluid is recommended: equal parts of glycerin and 95 per cent. alcohol with a very little formalin.

For collecting plant material either vascula or tins are indispensable. Some students like to press and dry their botanical specimens, and in connection with ecological work it is very useful. For this purpose a small botanical press is quite inexpensive and very efficient, because to get good results pressure and some absorbent medium are needed.

2. FIXING MATERIAL FOR MICROSCOPIC WORK

When it is desired to prepare sections to show nuclei and cell contents well, the material should be killed in a fluid which will penetrate quickly, so that disintegration does not go on while the specimen is dying. This is known as fixing the material. Fleming's solution and Bouin's fluid are fixatives easily used and give good results. One per cent. glacial acetic acid and 5 per cent. formalin in 1 per cent. sodium chloride are good fixatives for animal tissues. Small plants and animals and reproductive bodies are easily and efficiently fixed by holding them over the vapour of glacial acetic acid.

3. SECTION CUTTING

A hand microtome is within the reach of many students who have not got access to a more elaborate machine, and is very useful for cutting root-tips which are small and soft, for animal tissues, also anthers, ovaries, and other bodies, the contents of which fall out unless somehow held in place. To use a microtome for cutting, the material must be embedded in paraffin wax. This is rather a

long process. The material should be fixed in Fleming's solution, then adequately washed in water. It must then be dehydrated with alcohol. It is important that the change from one solution to another should not be sudden, or plasmolysis will occur. The specimen should be put from water to 25 per cent. alcohol, then to 50 per cent. alcohol, then 75 per cent. alcohol, then absolute alcohol, being left about twelve hours in each. At the absolute alcohol stage it is important to introduce with the material as little liquid as possible. It is advisable to use a second portion of absolute alcohol for a further period of twelve hours. The next stage is to replace the alcohol with a wax solvent. Xylol is very good for use here. A mixture of absolute alcohol and xylol should be used first, about 35 per cent., then 75 per cent., then pure xylol, which, like the absolute alcohol, should be repeated.

At this stage the material will be very transparent. It now requires placing in some paraffin wax which melts at about 48° C., and can be kept just melted for twenty-four hours. To remove the specimen prepare some small receptacle by warming it and greasing it with a little glycerin; prepare also a bowl of cold water, and warm a pair of forceps. Pour out sufficient wax, place the specimen in it, then hold the receptacle in the cold water so that the wax at the bottom and sides cools quickly. The surface very soon forms a skin over if it is gently blown on. The whole receptacle can then be submerged in water and left for the wax to solidify all through. It can then be cut to make a suitable rectangular block with the specimen in the centre. This can be affixed to the microtome adaptor.

Slides should be prepared to receive microtomed sections by putting on them a very thin film of egg albumen. This is made from the white of an egg, with an equal quantity of glycerin added, and a little salicylic acid. Cover the film with water, and into this place the sections with the side that was next the razor downwards. The slide should then be warmed slightly, when the wax and section will flatten. The surplus water can be removed with blotting-paper, and the slide left to dry in a warm place, but the wax must not be allowed to melt.

When thoroughly dry, the section should be firmly stuck to the slide. Remove the wax with xylol. The xylol should be removed by absolute alcohol, then dilute alcohol applied, and if necessary water, according to the stain it is desired to use.

4. STAINING

For hand sections of SOFT MATERIAL, **Methyl Green,** 1 per cent. in water with a trace of glacial acetic acid gives good results. The section should be submerged in the stain for about ten minutes. Then wash it in water. It can be mounted in dilute glycerin (50 per cent. glycerin in water). For FUNGI, good results are obtained by mounting them in dilute glycerin with a trace of

methyl green in it, and then leaving them for a few hours. The stain is absorbed by the Fungus making it green in a medium nearly or quite colourless according to the amount of stain which was added.

Specimens mounted in dilute glycerin may be rendered permanent by sealing the coverslip to the slide with Canada balsam, gold size, or specially prepared enamel. The strength of the glycerin can be increased gradually before sealing. Glycerin jelly can be used as a mounting medium; it must be warmed sufficiently to liquefy it, for the insertion of the material. Farrant's medium preserves the colour and natural appearance rather better than the above, and dries at the edges of the cover-slip making sealing much easier. Specimens can be mounted in Farrant's medium from water or dilute glycerin, the latter being preferable.

The AERIAL MYCELIUM of fungi often presents a difficulty, because it does not become wet, but remains surrounded by air-bubbles. This can be avoided by placing the mycelium in a 0·5 per cent. gelatin solution or a soap solution. It must then be immersed in water, in which it can be mounted for examination. After washing it can be mounted in lacto-phenol and sealed.

If the material is not too delicate it can be dehydrated, after washing, with alcohol. From water it should be put into 25 per cent. alcohol, then 50 per cent., then 75 per cent., and finally absolute alcohol. Great care must be taken in the last case that no water is introduced from elsewhere. A section being very thin, about five minutes should be long enough in all except the absolute alcohol stage, when rather longer and perhaps a second treatment may be found necessary. From absolute alcohol, sections can be put into clove oil. (Should any cloudiness appear dehydration is not complete.) They can also be mounted in clove oil if they are only needed for immediate examination. If permanent preparations are required the sections should be left in clove oil about fifteen minutes, then mounted in Canada balsam (dissolved in xylol), which will set hard after a time.

When MATERIAL is WOODY two stains can be used with advantage. A good combination easy to use is 1 per cent. **Basic Fuchsin** or 1 per cent. **Safranin** dissolved in 50 per cent. alcohol and **Light Green** dissolved in clove oil. Place the section cut from material preserved in spirit into the fuchsin (red), and leave for about five minutes. Then dehydrate. (Leave it longer in the 50 per cent. alcohol if it seems very darkly stained.) From absolute alcohol put it into Light Green, and leave for about five minutes. Then wash in clove oil, and mount either in clove oil or Canada balsam as desired. The red stain should appear in the wood and sclerenchyma, and the green in all the soft tissues.

Basic Fuchsin and **Methyl Green** also make a good combination. Use fuchsin, then dilute alcohol, then water, then the methyl green, then water, then the alcohols, then clove oil.

Delafield's Haematoxylin is also a very good stain for general purposes. It is useful for both PLANT and ANIMAL MATERIAL. This stain is made by dissolving 1 grm. of haematoxylin in 6 c.cm. of absolute alcohol: add this to 100 c.cm. of a saturated solution of ammonium alum; expose to light and air for a week; filter and add 25 c.cm. of glycerin and 25 c.cm. methyl alcohol. It must be kept for about two months before it is ready for use.

To use haematoxylin, the material must be placed in distilled water first. The stain should be applied for ten minutes. The material must then be washed in distilled water, and then placed in tap water for about fifteen minutes, during which time the slight alkalinity of the tap water will change the colour of the haematoxylin from reddish to dark blue. The material can then be dehydrated with alcohol and treated with clove oil as in the above cases.

It is often better to use a counterstain. The haematoxylin will stain the protoplasm and nuclei, and **eosin**, or **erythrosin**, used after the tap water, and, followed by dilute alcohol, will stain the cell walls.

For WOODY MATERIAL, **Safranin** and **Delafield's Haematoxylin** give good results. The material should first be put into 1 per cent. safranin in 50 per cent. alcohol. It is sometimes advisable to leave it in this stain for twenty to thirty minutes. Wash with dilute alcohol, then distilled water, and it will be ready to treat with haematoxylin as above.

SMALL motile ANIMALS and PLANTS are interesting and instructive to watch alive. If their movements are too rapid they can be inhibited by adding a little glycerin to the water in which they are mounted. PARAMECIUM and HYDRA can be induced to discharge their trichocysts by the addition of a little acetic acid or iodine. If it is desired to stain these small forms of life, they can be killed by adding a very little chloroform, ether, or a few menthol crystals to the water. They must then be fixed. Alcoholic **methylene blue** or Delafield's Haemotoxylin diluted 1 part in 10 of water are good stains for them. SPIROGYRA and similar ALGAE need fixing for several hours in 10 per cent. formalin. Then after washing in distilled water they can be stained with Delafield's Haematoxylin, diluted 1 part in 10 of 30 per cent. alcohol. They must then be washed in 40 per cent. alcohol, and the alcohol gradually strengthened to 75 per cent., when they can be counterstained with eosin in 75 per cent. alcohol. After this they can be dehydrated, cleared in clove oil or xylol, and mounted in Canada balsam.

Borax Carmine is a good stain for animal tissues. This consists of 1 grm. carmine, 2 grm. borax, in 100 c.cm. 70 per cent. alcohol. A little acid alcohol may be needed to remove the excess until a bright scarlet colour is obtained.

LIVER-FLUKE (*Distomum*) can be mounted whole. It can be fixed with absolute alcohol and pressed between two slides. Borax carmine is a suitable stain. It needs dehydrating and clearing with clove oil or xylol.

CILIATED EPITHELIAL CELLS can be obtained by scraping the roof of a frog's mouth. If they are mounted in normal saline solution the movement of cilia can be watched. Irrigate the slide with **acid fuchsin**, the ciliary action will gradually stop and the nuclei become stained. Other EPITHELIAL CELLS can be obtained from the lining of your own cheek, the lining of a frog's stomach, also similar parts of other animals. They can be treated as above for examination. They can also be spread out on a slide to dry, fixed in 5 per cent. formalin or 70 per cent. alcohol, after suitable washing stained with Delafield's haematoxylin and eosin, dehydrated, cleared with clove oil and mounted permanently. **Picro-carmine** is another suitable stain for these tissues.

It is sometimes a good plan to dilute the stain with its solvent, so that material may be left in it a little longer and thus the parts become more differentiated without being over-stained.

A piece of frog's bladder shows UNSTRIATED MUSCLE well, when treated as follows:—

Cut the bladder open and place a portion on a clean slide with the inside facing upwards. Stretch a portion of this as fully as possible by using needles. Keep this part moist, but allow the edges to dry, and it will become firmly attached to the slide. Pieces of loose epithelium should be removed with a small, wet camel-hair brush. Then fix with absolute alcohol for five minutes. Transfer to 75 per cent., then 50 per cent., then 25 per cent. alcohol, then distilled water, leaving about two minutes in each. Then stain with haematoxylin as above. **Orange G.**, 1 per cent. in absolute alcohol, may be applied for a moment before the absolute alcohol if desired. The surplus of this should be washed out with 90 per cent. alcohol before proceeding.

When it is specially desired to show NUCLEI, **Iron Haematoxylin** is very good. This stain involves the use of two solutions, first 3 per cent. aqueous solution of ammonium sulphate of iron (ferric), then ½ per cent. haematoxylin in distilled water. The material must be prepared with distilled water and washed between the two solutions, and after the application of the second, with distilled water. Both should be applied for at least fifteen minutes. Then wash with 25 per cent. and 50 per cent. alcohol, then examine microscopically. It is almost always found necessary to apply a little **acid alcohol** to differentiate the tissues with this stain, which is almost black in some parts, *e.g.* chromosomes, but with acid alcohol can be made quite faint in the other parts. One or two drops of hydrochloric acid are added to absolute alcohol to make it acid. It should only be applied for a second or two, and the section placed again into dilute alcohol for washing and examination. Eosin or erythrosin can be used with it, if desired. The material is then treated with absolute alcohol, then clove oil, and mounted as above.

STRIPED MUSCLE can be obtained from the leg of a frog, etc. A suitable fixative is 5 per cent. formalin in 1 per cent. sodium chloride,

or 2 per cent. potassium bichromate. This material needs well teasing out with two mounted needles, and this is best done in distilled water, after fixing. Iron haematoxylin, or Delafield's haematoxylin with eosin, or alcoholic methylene blue, or borax carmine give good results. Further teasing out can be done after staining if desirable. This material can be mounted and teased out in normal saline solution for immediate examination.

WHITE FIBROUS TISSUE can be obtained from the tendon of a toe of the hind limb of a frog. This can be mounted in normal saline solution for examination. It needs teasing out rather finely by drawing the needles longitudinally through it. For staining it should be fixed in 70 per cent. alcohol for about half-an-hour.

Place a piece of the membrane from the sub-cutaneous lymph spaces in the frog in dilute acetic acid for a few minutes, then spread it out on a slide in dilute glycerin. The acid will have dissolved the white fibres and left the YELLOW ELASTIC FIBRES amongst some cells of the connective tissue.

Sections of CARTILAGE can be cut from the skeleton of dogfish, from the cartilage covering the epiphysis of the femur of frog, and the ear trumpet of rabbit. After they have been fixed and hardened in methylated spirit this tissue can be stained with Delafield's Haematoxylin and eosin, borax carmine, or alcoholic methylene blue.

Take a piece of the sciatic NERVE of a frog and tease it out in normal saline solution, compare this with a piece teased out in dilute glycerine after the medullary sheath has been blackened by immersion in a 1 per cent. solution of osmic acid. Treatment with acid fuchsin will bring out the nuclei. After fixing, nerve tissue should be stained with iron haemotoxylin, methylene blue, or borax carmine. A portion of the sympathetic system can be similarly treated, and nerve cells observed in the teased ganglia.

The SALIVARY GLANDS of cockroach can be dissected out in water, floated on to a slide, and fixed in 70 per cent. alcohol. Borax carmine is a suitable stain. They take some time to dehydrate.

Hard substances, *e.g.* TEETH and BONE, can be softened in a ½ per cent. aqueous solution of chromic acid to which concentrated nitric acid is added. The quantity of the latter needed depends upon the size and hardness of the material. The process may take two or three weeks. The material must then be thoroughly washed. It can be soaked in a 10 per cent. solution of sodium bicarbonate for 10 to 15 hours to remove the acid and then further washed. Bones, *e.g.* in a rabbit's skull, can be softened by this process so that the head can be cut in half and the parts examined in situ. This needs a good strength of nitric acid.

CHITINOUS OBJECTS, such as the mouth parts of cockroach, need to be boiled in strong caustic potash or soaked in it for about 12 hours; then, after thorough washing, they can be dehydrated, cleared in clove oil, and mounted.

To make a stained preparation of BLOOD, place drops of blood on a clean slide or coverslip, and place another clean slide or coverslip at

an angle of about 45°, and draw it along so that a thin film of blood is obtained. Dry completely in air, warm slightly by passing through a Bunsen flame two or three times, to coagulate the serum. Then fix by putting the film into 90 per cent. alcohol for ten minutes. Then treat with 70 per cent., 50 per cent., 25 per cent. alcohol, then distilled water, then Delafield's haematoxylin for ten minutes or more. Wash with distilled water, treat with tap water for fifteen minutes, then with 25 per cent., 50 per cent., 75 per cent., and absolute alcohol, then clove oil. This could be counterstained with eosin in 90 per cent. alcohol, when the nuclei will be blue and the red corpuscles red. **Leishman's stain** can be used without fixing; the red corpuscles will be orange-pink and the nuclei blue. **Borrel's methylene blue** and aqueous-eosin, both very dilute, give red-pink red corpuscles and blue nuclei. Blood needs treating rather longer with the stains than most material.

For the examination of SPERMS or OVA, normal salt solution (.75 per cent.) should be used.

To make a permanent slide a film, or smear, should be obtained. Breathe well on the slide to make it damp. Cut off a piece from the vescicula seminalis, *e.g.* of an earthworm, and trail the open end gently over the central part of the slide. Dry and warm very slightly as for blood. Fix and stain with haematoxylin in the same way.

BACTERIA, if warmed slightly and allowed to dry on the slide, will adhere to it. They can then be stained with Carbol Fuchsin, which is 1 grm. fuchsin, 5 grm. carbolic acid crystals, 10 c.cm. 90 per cent. alcohol, and 100 c.cm. water. Another good bacteria stain is Gentian Violet, which is 1 grm. in 20 c.cm. of absolute alcohol, 80 c.cm. of water, and 3 c.cm. of anilin oil. In both cases the slide should be well washed in water and then be dried and examined in clove oil or mounted in Canada balsam. (They can be dehydrated in the usual way if preferred.)

5. GERMINATION OF POLLEN TUBES

Microscope slides can be obtained with a hollow in the centre, over which a coverslip can be put so that there is a little cavity between the coverslip and slide. Put a drop of 5 per cent. cane-sugar on a coverslip and sow some ripe pollen grains in it, then invert it over the hollow in the slide. If placed in a warm, dark place they will begin to germinate in a few hours. Narcissus pollen grains germinate very quickly. They can conveniently be watched under the microscope if sown this way.

If slides of this kind are not available the pollen grains can be grown in watch-glasses and a drop mounted from time to time.

Some pollen grains need stronger sugar solution.

Other **spores** can often be watched germinating in a similar way. Many will start in water; otherwise food must be supplied according to the nature of the plant to which the spores belong.

6. KEEPING LIVE CREATURES

Tiny water creatures can be kept in beakers or shallow dishes with a few sprays of some water plant, provided they are fed. *Amoebae* will live satisfactorily on a diet of liquid in which barley grains have been boiled. This can be added to the water once a month. *Paramecium* prefers an infusion of hay. Small crustacea. such as *Daphnia* and *Cyclops*, popularly known as water fleas, will multiply if given a little milk every three days; and these tiny animals are useful to put into aquaria containing water boatmen, etc., where they will provide food for the larger animals. *Hydra* also can be fed on them. The feeding of larger creatures in aquaria has already been dealt with in Chapter XXXI. In filling an aquarium it is well to remember that the water may contain lead salts, which are poisonous. These will be largely removed if the tap is allowed to run for a time before the water is used.

It is easy to obtain **frog** spawn and allow it to hatch into tadpoles, and these for some time are vegetarians, but when they acquire their first legs they really need some meat food in order to flourish. Tiny pieces of raw meat may be hung in the water on cotton, and removed after a few hours. When the tadpoles have become frogs it is difficult to keep and feed them. A few may be kept in a vessel with damp turf or moss and a shallow dish of water for a time, and plant material covered with aphides put in frequently to provide food.

If a pair of frogs are put into an aquarium in early March, they will probably mate, and spawn may thus be obtained. This aquarium will need a covering, and indeed this is usually advisable: the covering may be made of muslin or perforated zinc.

Fig. 537. A LARVA CAGE.

Caterpillars may be kept very satisfactorily provided the food plant is known. A convenient vessel in which to keep them is shown in Fig. 537. In this, muslin supported by wire rings, is used. This can be replaced by a bell-jar with muslin over the top.

A **wormery** is very instructive and quite easy to manage. All that is needed is a rather large, preferably rectangular, box, constructed so that it has a perforated zinc bottom, and two glass sides. The remaining sides may be glass, perforated zinc, or just part of the wood or metal framework. The perforated bottom must be raised a little for drainage; and it is convenient to have a tray beneath it to catch the water which drains through. Into this box should be placed a layer of gravel with large enough stones not to pass through the perforations at the bottom, then a layer of soil, and above this a layer of fine sand, above this again another layer of soil, and on top some pieces of leaves and plant material which will in time make humus, and will serve for the worms' food. A supply of garden worms, earthworms, must be put

in, and the whole must be kept damp. The movements of the worms can be followed by means of the sand which they will move. They will also move the vegetable matter from the surface. A perforated cover may be placed on top. The depths of the layers of soil, etc., can be adjusted according to the size of the case, and additional layers may be added if space permits.

7. KILLING ANIMALS

Larger animals, *e.g.* frog and rabbit, should be enclosed in an airtight vessel with some cotton wool soaked in ether or chloroform. Insects can be killed with chloroform or potassium cyanide, but this must be handled with care. Take a bottle fitted with a ground-glass stopper or air-tight cork, fill it to nearly a third of its depth with potassium cyanide, and pour over this a thin layer of plaster of Paris mixed with water to form a paste, which must set firm on drying. If the insect is in a thin wooden "pill box," the box containing it can be put into a jar containing blotting-paper soaked in strong ammonia. Aquatic animals such as mussel can be killed by the addition of a little chloroform or ether to the water. The mussel shell can be wedged open a little with a piece of wood or stiff roll of paper.

APPENDIX (2)

THE EDIBLE SNAIL

The MOLLUSCA, the phylum to which Swan Mussel belongs, includes another class in which are some well-known types, namely the GASTROPODA. Many of them live in the sea, but some are fresh water animals, and to it belong the terrestrial snails and slugs. In contrast to the bivalves, the shell is all in one piece, the body is flattened from above downwards and the visceral hump is spirally twisted to match the shell. They have heads, with eyes and a rough tongue or radula, which are not found in mussel.

The large edible species of snail, *Helix pomatia*, is common on the Continent. The common British garden snail, *Helix aspersa*, is another species of the same genus. They are very similar except in size. The **shell** is a right-handed spiral. It is lined by a fold of skin, called the **mantle**, and it is enlarged by secretion from the thick mantle margin around the mouth of the shell. It consists of an organic substance conchiolin, and carbonate of lime, and is in three layers. The outermost layer is coloured, thin, and

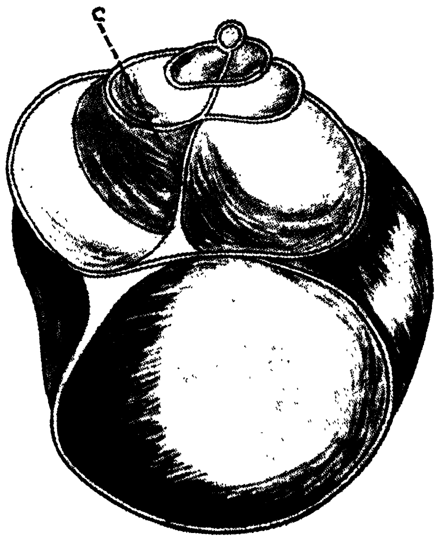


Fig. 1. HELIX POMATIA.
Shell cut to show the Columella C.

can be rubbed off; the middle layer is thick and the inner layer is pearly. The cavity in the shell is continuous and the body extends into the whole of it. The inner walls of the coils form a pillar, the **columella,** and a strong muscle attaches the animal to this (Fig. 1). The smallest and uppermost part of the spiral is the oldest piece of the shell.

The animal creeps along on the muscular ventral surface and this is therefore called "the **foot**" (Fig. 2). As it travels along it leaves a slimy trail of mucus. This substance, secreted by glands in the foot, oozes out by a duct opening just beneath the mouth (Fig. 3); it helps it to slide along easily. The **head** bears a long and a short pair of **tentacles**, which the animal can pull inwards. The long ones, which bear the eyes on the end, are always retracted first. If the animal is removed from the shell, the skin is seen to vary, being very thin on the visceral hump.

The snail is a vegetarian and tears pieces from leaves by means of the **radula**, which is a membrane bearing rows of small teeth made of chitin (Fig. 4). It rests on a cartilaginous pad on the floor of the mouth or buccal cavity, and is continued behind into a radula sac within which it grows continually to make up for the wearing away of its anterior (Figs. 3 and 4). Protractor and retractor muscles enable it to move up and down, and backwards and forwards, and its movements within the mouth produce a suction, which, together with the muscular lips and cilia in the mouth-cavity, draws food particles inwards. The radula, pad and muscles together make up the odontophore. In the roof of the buccal cavity is a hard, crescent-shaped plate against which the radula works.

There are two large, lobed, **salivary glands,** the ducts of which open on the dorsal surface of the **buccal cavity.** The **oesophagus** leads from the buccal cavity and expands into the **crop,** alongside which lie the salivary glands (Fig. 3). The crop is for storage and opens into the **stomach,** where digestion occurs. From the stomach leads out the coiled

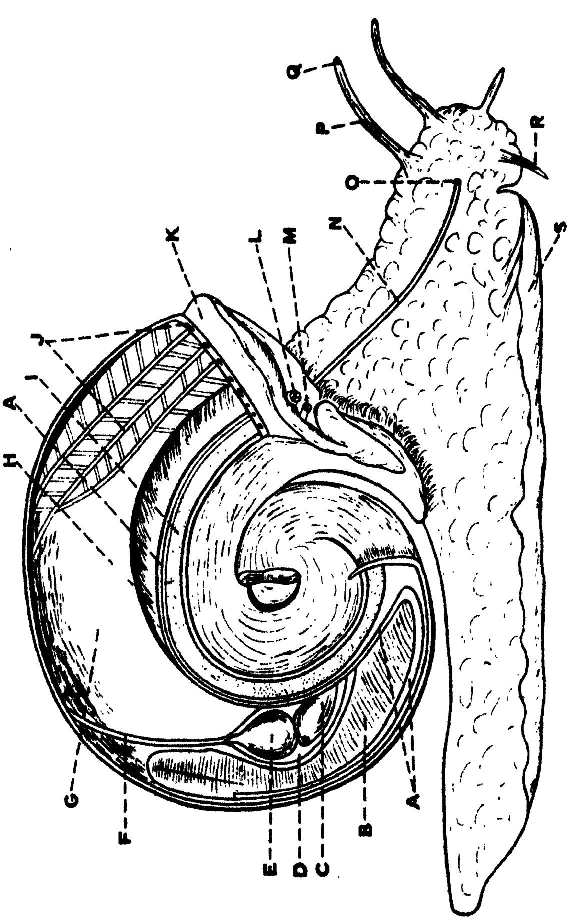


Fig. 2. Helix Pomatia. The right half of the Shell and the upper part of the Spiral Visceral Mass have been removed. A, ureter; B, kidney; C, ventricle; D, pericardium; E, auricle; F, pulmonary vein; G, mantle cavity; H, dorsal body wall (floor of the mantle cavity; I, rectum; J, pulmonary vessels; K, edge of the mantle; L, respiratory aperture; M, anus; N, groove leading to the genital aperture O; P, posterior tentacle; Q, eye; R, anterior tentacle; S, foot.

intestine, which is embedded in the liver. The last part of the intestine, the **rectum**, runs forward and then opens towards the anterior of the animal's right side close by the respiratory aperture. The walls of this alimentary canal are muscular and it is partly lined with cilia.

The **liver** is large, and is very much more than a liver, for in addition to storing glycogen and phosphate of lime, it produces several enzymes for digesting many kinds of food. These enzymes pass along ducts into the stomach (Fig. 3). It has two parts: one is situated in the first turn of the spire and this is the larger and more or less subdivided into three lobes. The main ducts from this part unite into one which opens into one side of the stomach. The second part of the liver is in the second and third turn of the spire and a duct from it enters the other side of the stomach. The liver contains a greenish pigment, called enterochlorophyll. In an animal removed from the shell, this large greenish-brown, digestive gland can be seen through the skin, occupying the greater part of the visceral hump. The coiled intestine also shows through and is somewhat bluish in colour.

The **circulatory system** comprises a heart, arteries, venous spaces and veins. The blood contains a pigment, haemocyanin, which gives it a bluish tinge when oxygenated, and also some colourless, amoeboid cells. The **heart** has a ventricle and an auricle and is surrounded by a pericardium (Fig. 2). It is situated dorsally and to the left side. From the ventricle, oxygenated blood flows along **cephalic** and **visceral arteries** to head, body and foot. It passes into narrow spaces among the various tissues and thence into larger **venous spaces,** whence it collects in a network of **pulmonary vessels** on the dorsal surface of the lung cavity. Here it is oxygenated and returns to the auricle by a **pulmonary vein,** which receives a **renal vein** from the kidney.

The pulmonary, or lung, cavity is really the **mantle cavity,** being bounded dorsally by the mantle and ventrally by the dorsal surface of the animal's body. Air passes into and out of it by the respiratory aperture, which is on the right side of the body close to and anterior to the anus (Fig. 2).

The excretory organ is a triangular, greyish **kidney** lying between the heart and the rectum (Fig. 2). It is

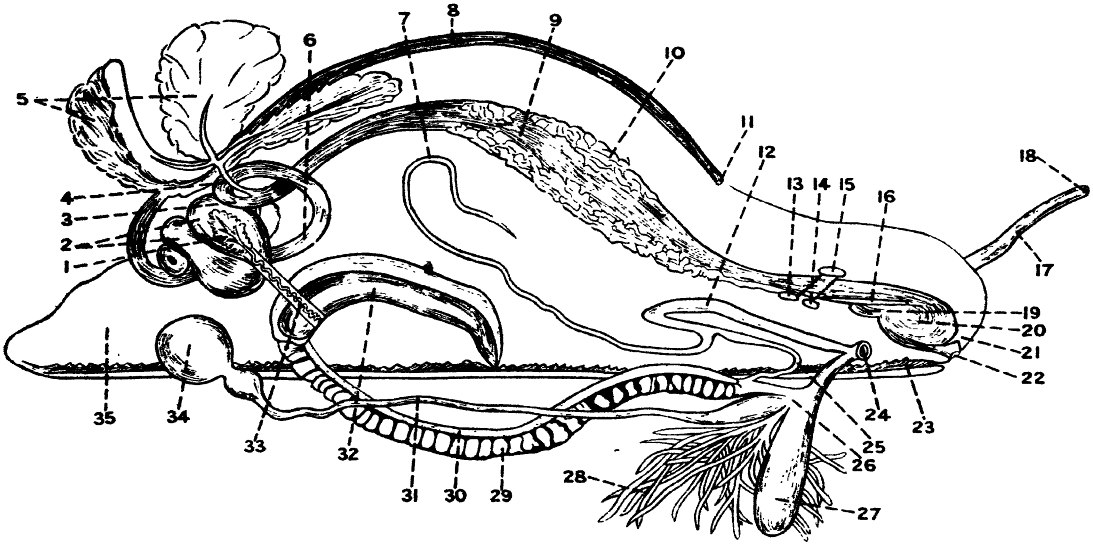


Fig. 3. HELIX POMATIA. DISSECTION TO SHOW THE DIGESTIVE AND REPRODUCTIVE SYSTEMS.

1, hermaphrodite gland; 2, liver of the second and third turn of the spire; 3, stomach; 4, duct from the liver; 5, liver of the first spire; 6, intestine; 7, flagellum; 8, rectum; 9, crop; 10, salivary glands; 11, anus; 12, penis; 13, viscero-pleural ganglion; 14, pedalganglion; 15, cerebral ganglion; 16, salivary duct; 17, posterior tentacle; 18, eye; 19, radula sac; 20, buccal mass; 21, jaw; 22, mouth; 23, mucus gland of the foot; 24, genital aperture; 25, vas deferens; 26, oviduct; 27, Cupid's Dart Sac; 28, mucous glands; 29, female part of the common duct; 30, male part of the common duct; 31, duct from the spermatheca, 34; 32, albumen gland; 33, hermaphrodite duct; 35, foot.

hollow and excretes nitrogenous waste into a **ureter,** which runs forwards and then by the rectum on the animal's right side and opens close by the anus. The kidney communicates by a small aperture with the pericardial cavity.

The **nervous system** forms a ring round the oesophagus. There are three pairs of ganglia, the cerebrals placed dorsally, and the pedals and viscero-pleurals placed ventrally (Fig. 3). The last gives off nerves to the mantle and

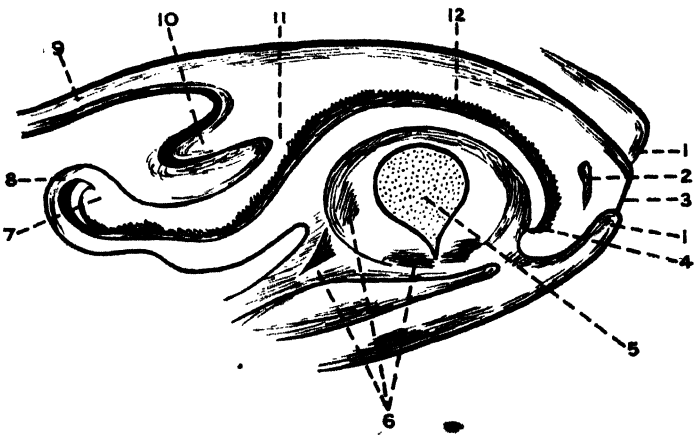


Fig. 4. SECTION THROUGH THE BUCCAL AREA OF HELIX.
1, the lips; 2, left jaw; 3, mouth; 4, anterior end of radula; 5, cartilaginous pad on the floor of buccal cavity; 6, muscles; 7, cells which produce new teeth; 8, radula sac; 9, oesophagus; 10, fold in oesophagus wall behind radula sac; 11, opening of the radular sac into the buccal cavity; 12, radula.

posterior organs, the pedals supply nerves for the foot and from the cerebrals pass nerves for all the structures of the head.

The **eyes** are cups formed by an infolding of the epidermis. Each is supplied by a nerve from the cerebral ganglion, and the lining in the base of the cup consists of cells somewhat similar to those of the retina in more advanced types

of eye. The cup is filled with a clear body reminiscent of a lens and it is closed in front by a transparent layer. The **ear sacs**, or otocysts, are two small, white spots, one on each pedal ganglion. They contain fluid and a number of oval otoliths of lime, and some of the lining cells are ciliated. The snail has a **sense of smell**, which guides it to desirable food and away from undesirable substances. This sense appears to be due to sense cells at the tips of both pairs of tentacles. On the lips are cells probably giving a **sense of taste**. There are cells sensitive to **touch** in the skin on the sides of the foot and on various parts of the body.

The snail is **hermaphrodite**, but in spite of this they pair and thus effect **cross fertilisation**. The main organ of the reproductive system is whitish and can be seen through the skin near the apex of the visceral hump. It is called the **ovo-testis** and consists of a number of cylindrical bags in which both ova and spermatozoa are formed, but not both at the same time. A twisted hermaphrodite duct leads from the ovo-testis to a large **albumen gland**, which forms protein material that envelopes the ova (Fig. 3). From the hermaphrodite duct a **common duct** passes forwards towards the head. It has a female part, for the passage of ova, incompletely separated from a male part, for the passage of sperms. The former is larger and has a puckered wall. At the end of the common duct is a **vas deferens**, which twists round and leads into a muscular **penis**, which can be protruded through the **genital aperture**, an opening quite close to the mouth. At the junction of vas deferens and penis is a long, narrow **flagellum** in which the sperms agglutinate and form a body called the spermatophore. This passes into the penis, there to complete its development, and to be transferred into the genital aperture of another snail. Leading from the female part of the common duct is a short **oviduct** leading to the genital aperture. Opening into the oviduct are two structures. One of these is a long, narrow duct from a rounded **spermatheca**

into which passes the spermatophore from another snail. The sperms from this are freed to fertilise the eggs of the snail which has received them. Also leading into the oviduct is a **mucous gland** consisting of two sets of finger-like processes; its secretion forms the calcareous egg shells. The very small chamber into which lead penis and oviduct, and which opens in the genital aperture, may be called the vagina, and into it opens a large, cylindrical sac with muscular walls called **Cupid's Dart Sac.** It contains a pointed, calcareous dart, which is jerked out of the sac immediately before the snails pair. A new one is formed after they have separated. During the pairing they exchange spermatophores, the sperms from which will fertilise their eggs.

The **eggs** are laid in the soil in June and July, each surrounded by a gelatinous material and an elastic, calcareous shell. In about three weeks small snails, exactly resembling the adult, hatch from them. In AQUATIC GASTROPODS, e.g. *Limnaeus*, the **pond snail,** there are two larval stages, namely the trochosphere followed by the veliger, before the adult stage is reached.

It will be noticed that the snail is **asymmetrical**, due to the twisting round to the right side of the part of the body containing the viscera. The head and foot are bilaterally symmetrical. The twisting is due to the vertical development of the visceral hump and the growth on it of a heavy shell. This twist accounts for the alimentary canal ending on the right side of the body near the head, and for the presence of only one kidney.

In winter the snails **hibernate.** They bury themselves in the soil and then close the mouth of their shell with hardened mucus and lime.

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PRINTED IN GREAT BRITAIN BY UNIVERSITY TUTORIAL PRESS, LD. FOXTON, NEAR CAMBRIDGE